PRELIMINARY MINING REPORT FOR LAND EXCHANGE APPLICATION

BETWEEN

THE STATE OF UTAH AND THE UNITED STATES OF AMERICA

BY

JAMES D. RUSH

RANDY D. HEUSCHER

JOHN W. MILEY

U. S. DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
CONSERVATION DIVISION
OIL SHALE OFFICE

NOVEMBER 1981

STATE OF UTAH EXCHANGE

Table of Contents

STATE OF UTAH EXCHANGE

Abstract

Oil shale in-place and recoverable resources are evaluated and compared between selected Federal lands and offered Utah state lands. Selected Federal lands contain 848 x 10^6 BBL of in-place resources in the Mahogany Zone, compared to 1,330 x 10^6 BBL of in-place resources on Utah offered lands. Estimates of recoverable resources based on the room-and-pillar mining method and the preferred direct stress method of analysis are 457 x 10^6 BBL for the Federal selected land and 424 x 10^6 BBL for the state offered land. The difference of 7% probably lies within the limits of accuracy of the analysis.

The procedure used in this report to estimate recoverable resources considered the effect of mine depth, rock strength, mine pillar design, and Mahogany Zone stratigraphy on resource recovery. The average depth to the mining zone on the offered state lands is 2150 feet, whereas the average depth to the mining zone on the Federal selected lands is 935 feet.

Evaluation of the effect of this depth difference between offered and selected lands on mining costs, mine profitability, or potential royalties is beyond the scope of this analysis.

I. Purpose:

This report is the result of preliminary evaluation of an application from the State of Utah for the exchange of selected Federal oil shale mineral estates for offered oil shale mineral estates presently owned by the State of Utah and leased to the Quintana Corporation. The legal descriptions and acreage of selected Federal lands and offered state lands are summarized in Tables 1 and 2, respectively.

TABLE 1. PUBLIC LANDS SELECTED FOR EXCHANGE

Township 9 South, Range 25 East, SLM
Uintah County, Utah

Section	Description	Acres
1	Lots 1, 2, 3, 4, 5, SW1/4 NW1/4, W1/2S W1/4 (All)	269.68
9	All	640.00
10	All	640.00
11	All	640.00
12	Lots 1, 2, 3, 4, W1/2 W1/2 (All)	275.86
13	Lots 1, 2, W1/2 NW1/4	138.36
14	N 1/2	320.00
15	N 1/2	320.00
17	Lots 1, 2, 3, 4, 5, 6, NE1/4 NE1/4, SW 1/4 NW 1/4, S 1/2	604.35
20	All	640.00
21	All	640.00
22	Lots 2, 3, SW 1/4 NW 1/4	58.07
29	Lots 1, 2, 3, 4, NE 1/4 SW 1/4, SE 1/4, N 1/2	617.92
		5804.24

The selected lands involved in the proposed Utah land exchange (land descriptions and acreages provided by Quintana Corporation).

TABLE 2. UTAH STATE LANDS OFFERED FOR EXCHANGE

Utah Oil Shale Leases
Uintah County, Utah

Lease No.	Description		Acres
ML 20732	T9S, R24E		
	Section 29:	All	640.00
ML 20740	T9S, R24E		
	Section 32:	NE 1/4 NE 1/4, S 1/2, NW 1/4, S 1/2	440.00
ML 20758	T8S, R25E		
	Section 36:	Lots 1 through 4, W 1/2 W 1/2	275.16
ML 20759	T8S, R25E		
	Section 32:	All	640.00
ML 20760	T8S, R24E		
	Section 36:	All	640.00
ML 20761	T8S, R24E		
	Section 32:	All	640.00
ML 20762	T8S, R23E		
	Section 36:	All	640.00
ML 20763	T8S, R23E		
	Section 32:	All	640.00
ML 20764	T8S, R22E		
	Section 36:	All	640.00
ML 20765	T8S, R22E		
	Section 31:	Lot 3, NE 1/4 SW 1/4, SE 1/4	
	Section 32:	All	879.75
ML 20784	T9S, R24E		
	Section 15:	Lots 1 through 4, N 1/2 N 1/2 SE 1/4, NW 1/4 SE 1/4, N 1/2, N 1/2 SE 1/4, NW 1/4 SW 1/4, N 1/2 SW 1/4 SW 1/4, SW 1/4 SW 1/4 SW 1/4, N 1/2 SE 1/4 SW 1/4 SW 1/4, SW 1/4 SE 1/4 SW 1/4 SW 1/4	616.59
			6691.50

II. <u>Geology</u>:

A. Stratigraphy

The major economic mineral resource underlying both offered and selected lands is oil shale of the Green River Formation. The Green River Formation consists primarily of light-gray to dark-gray, hard, brittle marlstone and oil shale, interbedded with relatively minor amounts of brown sandstone, siltstone, nahcolite nodules, and thin volcanic tuff. The formation ranges in thickness from a minimum of 1400 feet in outcrops near the selected lands to a maximum of 7200 feet in the subsurface along the depositional axis of the Uinta Basin. The Green River Formation is divided into three members: the Douglas Creek, Garden Gulch, and Parachute Creek Members.

The basal unit of the Green River Formation is the Douglas Creek Member. It consists of relatively greater thicknesses of sandstone and limestone and minor thicknesses of oil shale. Oolites, algal mats, and ripple marks indicate that this member was deposited in the shallow, fresh waters of Eocene Lake Unita. Along the south and southwest margins of the basin, the Douglas Creek is only 200 feet thick. At the center of the basin, the Douglas Creek increases to a maximum thickness of 3000 feet.

Overlying the Douglas Creek Member is the Garden Gulch Member. It consists primarily of gray and brown marlstone with interbedded organic matter and minor amounts of siltstone, sandstone, and thin beds of oil shale. The Garden Gulch grades into equivalent beds of the Parachute Creek Member toward the center of the basin.

The uppermost Parachute Creek Member includes the Mahogany Zone, the most economically important sequence of oil shale strata in the Uinta Basin. The rocks are predominantly calcium carbonate mudstone (marlstone), and dolomite, both containing abundant organic matter, interbedded with volumetrically minor siltstone, sandstone, and altered volcanic tuff. Near Federal Oil Shale Lease Tracts Ua/Ub, outcrops along the southeast perimeter of the Uinta Basin attain a maximum thickness of 900 feet. Like the other Tertiary formations in the Uinta Basin, it thickens in the subsurface toward the depositional center of the basin.

The Mahogany Marker, an easily recognized, widespread key bed within the Parachute Creek Member, is commonly used to mark the stratigraphic position of the principal oil shale zone. The marker is a zeolitically altered volcanic tuff that averages 6 inches thick and lies 9 to 15 feet above the Mahogany Bed, the richest oil shale bed in the basin. The Mahogany Marker weathers to orange-brown rectangular blocks and lies within the upper portion of the Mahogany Zone, which crops out as a light-gray-tan resistant ledge.

Another remarkably distinctive zone occurs in the uppermost Parachute Creek Member. It is known informally as the "bird's nest zone"

due to its many ellipsoidal cavities formed by groundwater dissolution of nahcolite (a soluble sodium-bicarbonate mineral) from a matrix of predominantly siltstone and marlstone. This zone is the primary aquifer above the Mahogany Zone in the vicinity of the Federal Lease Tracts Ua/Ub and the Federal lands selected by the State of Utah.

Volcanic tuff occurs throughout the Parachute Creek Member and a particularly conspicuous sequence of thick, light-gray tuffaceous sandstone beds occurs above the "bird's nest zone." These beds create a yellowish-orange-weathering, ledge-forming sequence designated the "t" zone.

The Uinta Formation overlies the Green River Formation and is is exposed at the surface on the offered state lands. The Uinta Formation was deposited in variable alluvial, fluvial, lacustrine and deltaic environments in the Eocene Epoch. Along the northwestern margin of the Uinta Basin, it consists of continental boulder conglomerates. Along the eastern edge of the basin, the Uinta Formation consists of brown fluvial and deltaic sandstones with minor interbedded greenish-gray shale. In the central basin, thin bedded shale and dolomite with evaporate mineral molds were deposited as ancient Lake Uinta dried up. The Uinta Formation ranges in stratigraphic thickness from zero at the northwestern and western margins of the basin to approximately 5000 feet near the basin's depositional center.

B. Structural Geology

The Uinta Basin is an elongated east-west trending structural depression located 30 miles south and parallel to the crest of the Uinta Mountains. Major structural elements bounding the basin are the Douglas Creek Arch on the east, the Uncompahgre Uplift on the southeast San Rafael Swell on the southwest, and the Uinta Mountain uplift on the north.

Structural relationships within the Uinta Basin are relatively uncomplicated. Along the north margin of the basin the Eocene strata dip southward as much as 35° toward the basinal axis. Along the south and southeast margins of the basin, the strata dip slightly more toward the north than the present ground surface; dips range from 1° to 8° the north or northwest and flatten toward the basin center.

Several prominent northwest-plunging anticlines occur around the perimeter of the basin; the most notable of these extend from the west side of the Douglas Creek Arch near Bonanza, Utah, along the Colorado-Utah border.

The faults within the basin are relatively minor. Those present are essentially vertical, trend northwestward, and exhibit small displacements. A system of northwest-trending and northeast-trending vertical joints occur throughout the basin region. Most of these joints are open, smooth, well-defined, straight cracks in the rock. The most numerous and closely spaced joints occur in thin-bedded marlstone

and siltstone, although some joints do occur in the sandstone beds. Gilsonite veins fill some of the northwest-trending joints and minor faults in the central and eastern portions of the Uinta Basin.

III. Total In-Place Resources:

Estimates of the total barrels of oil underlying the selected and offered lands within the Mahogany Zone were calculated by the Salt Lake City Office, Resource Evaluation, Conservation Division, U. S. Geological Survey. The selected Federal lands are estimated to contain 848 x 10^6 barrels of in-place oil and the offered state lands 1,330 x 10^6 barrels of in-place oil. Table 3 summarizes these estimates.

IV. Mining Zone Selection:

The estimates of in-place or total resources (Table 3) do not realistically reflect the resources that could be extracted from the offered state or selected Federal lands. The room and pillar method (the only mining technique demonstrated for oil shale extraction) and the modified in-situ (MIS) method (now in the research and demonstration stage) do not extract all resources. Some oil shale is left behind as barrier and support pillars. In addition, the higher estimate of in-place resources (Table 3) on offered state lands simply reflects basinward stratigraphic changes in the Mahogany Zone. These lands lie over the depositional center of the Uinta Basin, where the Mahogany Zone is thicker.

For these reasons (mining loss and basinward stratigraphic changes), the Oil Shale Office, U. S. Geological Survey, selected a two-step evaluation technique. First, a logical mining interval, based on stratigraphic and geologic controls, was selected for each parcel of offered or selected lands. Second, a hypothetical mining plan, based on the state-of-the-art techniques for oil shale extraction, was prepared for each parcel.

To estimate mining intervals, stratigraphic cross-sections were prepared through the offered and selected lands. Plates 1-3 summarize stratigraphic, geologic, and shale oil yield information for the selected Federal (Plate 1) and offered state lands (Plates 2 and 3). For each parcel the mining interval selected would maximize resource recovery and minimize costs. For selected Federal lands, a 50-foot interval was chosen. Based on geological analysis, an interval larger than 50 feet would dilute the average grade (expressed in gal/ton) and increase marginal mining costs. The mining interval on three offered parcels (ML 20759, 20760, and 20758) is also 50 feet. All other parcels offered for exchange have a 60 foot mining interval.

The difference in mining interval (50 to 60 feet) corresponds to the basinward thickening of the Mahogany Zone. Offered and selected parcels near the eastern edge of the basin have thinner mining zones than parcels overlying the Uinta Basin's depositional center.

In this evaluation, only resources in the Mahogany Zone were estimated. Present development models for oil extraction in the Uinta Basin (White River Oil Shale Project [Ua/Ub], Tosco, and Magic Circle) indicate that only oil from the Mahogany Zone shales can now be profitably extracted.

TABLE 3
In-Place Resources in the Mahogany Zone

Utah State Leases	ESTIMATES OF RESOURCES (barrels of oil in place) 0 to 1-1/2 miles of data* MEASURED	1-1/2 to 3 miles of data* INDICATED	DEMONSTRATED RESOURCES (rounded to three significant figures)
ML20732	120,000,000	4,870,000	125,000,000
ML20740	75,300,000	-	75,300,000
ML20758	32,200,000	7,870,000	40,100,000
ML20759	30,200,000	74,900,000	105,000,000
ML20760	8,350,000	125,000,000	133,000,000
ML20761	1,730,000	121,000,000	123,000,000
ML20762	110,000,000	-	110,000,000
ML20763	-	167,000,000	167,000,000
ML20764	139,000,000	2,210,000	141,000,000
ML20765	135,000,000	50,700,000	186,000,000
ML20784	127,000,000	-	127,000,000

*Radius of influence

Offered Lands Total Resources 1,330,000,000 barrels of oil in place

Selected Lands Total Resources 848,000,000 barrels of oil in place

RESOURCE CALCULATIONS:

bbl oil in place = oil yield (gal/ton) x thickness (ft) x avg weight (lb/ft^3) x area (acres) x 0.51857

For each parcel, resources in the mining zone were computed using the following formula:

$$\text{BBLs oil} = \text{Area (acres)} \times (4.4 \times 10^{3}\ \text{ft}^2/\text{acre}) \times \text{thickness (ft)} \times$$

$$\text{density (tons/ft}^3) \times \text{yield (gal/ton)} \times \text{BBLs/42gal}$$

Results (BBL oil) were mathematically expressed to three significant figures and are summarized in Table 4. The selected Federal lands contain 610 x 10^6 BBLs of oil in a 50' mining zone. The offered lands contain 792 x 10^6 BBLs in a mining zone that increases from 50' to 60' thick in a basinward direction.

V. Mining Method Selection

The room-and-pillar method of resource extraction was chosen as the model for the offered and selected lands. This is the only method demonstrated for oil shale recovery and is the proposed method for Federal Lease Tracts Ua/Ub. Figure 1 shows a typical room-and-pillar mining layout. Figure 2 illustrates the location of barrier pillars between panels and the location of support pillars within panel boundaries. Figure 3 illustrates the pillar width (W) and room span (S) within a panel.

VI. Recoverable Resources

Recoverable resources were computed for mine panels of a hypothetical mine on each parcel of offered or selected lands. To calculate the percentage recoverable, the size of room spans and room widths was estimated by two techniques. The direct stress and confined core procedures (explained in the Appendix) give estimates of the size of room spans and pillar widths needed to support an opening 50 to 60 feet high in a shale of certain grade and at the given depth. Then, after the room span and pillar width were determined, the percentage of resources that could be recovered was estimated. The third procedure, proposed by Robert Merrill, assumes a straight line relationship between recovery and mining depth.

Tables 5, 6, and 7 summarize the recoverable resource in offered and selected lands. Using the confined core model (Table 5), the difference between resources on selected and offered lands is 4%. The Merrill Model, the use of which was proposed by Quintana Corporation, produces the largest difference (11%) between recoverable resources on offered and selected lands (Table 6).

The preferred method for design of pillar and room sizes is the direct stress method (see Appendix). Applying this technique to estimate recoverable resources (Table 7), offered state lands are estimated to contain 424 x 10^6 BBL of oil, compared to 457 x 10^6 BBL of oil on the selected Federal lands. The 7% difference in recoverable resources between offered and selected lands is believed to lie within the probable error and the uncertainty of the variables used in the computations.

The three techniques used to estimate recoverable resources consider the effect of depth, rock strength, and geologic controls on resource

TABLE 4
Resources In Mining Zones

Lease No.	Acres	Tons x 10^7	Barrels x 10^7	Grade gal/ton
Utah Offered Lands				
ML- 20732 20740	1080	19	13.6	30
20759	640	9.5	6.5	29
20760	640	9.2	7.2	33
20761	640	11.5	7.4	27
20762	640	11.5	7.5	27
20763	640	11.2	8.3	31
20764	640	11.3	8.1	30
20765	640	16	9.9	26
20758	295.16	4.1	2.8	29
20784	616.59	10.8	8.0	31
20739	625.36	9.2	6.6 x 10^7	30
TOTALS	2316.86	123.3 ~~114.1~~	85.8 ~~79.2~~	29.2
Selected Federal Lands				
Block 1		47	33	29.5
Block 2		38	28	30.5
TOTALS		85	61	30.1

TABLE 7 Direct Stress (w/ correction for W/H)

avg. depth = 2050'

Lease No.	Resources in Mining Zone: Tons x 10^7	Barrels x 10^7	Grade	Overburden	Mining Interval	Recovery %	Recoverable Resources: Tons x 10^7	BBLs x 10^7
Utah Offered Lands								
ML-20732 20740 1080	19	13.6	30	2025	60	55.9	10.6	7.6
20759 640	9.5	6.5	29	1530	50	67.2	6.4	4.4
20760 640	9.2	7.2	33	1855	50	60.8	5.6	4.4
20761 640	11.5	7.4	27	2260	60	52.5	6.0	3.9
20762 640	11.5	7.5	27	2510	60	49.3	5.7	3.6
20763 640	11.2	8.3	31	2770	60	45.1	5.1	3.7
20764 640	11.3	8.1	30	2765	60	45.1	5.1	3.7
20765 640	16	9.9	26	2790	60	45.1	7.2	4.5
20758 225.16	4.1	2.8	29	950	50	75	3.1	2.1
20784 616.59	10.8	8.0	31	2030	60	55.9	6.0	4.5
20737 625.36	9.2	6.6	30	1050	50	75	6.9	5.0
TOTALS 2316.86	~~114.1~~ 123.2	~~79.2~~ 85.8	29.2				~~60.8~~ 67.7	~~42.4~~ 47.4
Selected Federal Lands								
Block 1	47	33	29.5	940	50	75	35.2	24.7
Block 2	38	28	30.5	930	50	75	28.5	21.0
TOTALS	85	61			78,700 bbl/acre		63.7	45.7 43.3

64781 bbl/acre

Percent Difference 7%

TABLE 6 Merrill Model (S.F. = 2.5)

Lease No.	Resources in Mining Zone Tons x 10^7	Barrels x 10^7	Grade	Overburden	Mining Interval	Recovery %	Recoverable Resources Tons x 10^7	BBLs x 10^7
Utah Offered Lands								
ML-20732 20740	19	13.6	30	2025	60	60	11.4	8.2
20759	9.5	6.5	29	1530	50	70	6.7	4.6
20760	9.2	7.2	33	1855	50	65	5.8	4.7
20761	11.5	7.4	27	2260	60	55	6.3	4.1
20762	11.5	7.5	27	2510	60	50	5.8	3.7
20763	11.2	8.3	31	2770	60	44	4.9	3.7
20764	11.3	8.1	30	2765	60	44	5.0	3.6
20765	16	9.9	26	2790	60	44	7	4.4
20758	4.1	2.8	29	950	50	81	3.3	2.3
20784	10.8	8.0	31	2030	60	60	6.5	4.8
TOTALS	114.1	79.2	29.2				62.7	44.1
Selected Federal Lands								
Block 1	47	33	29.5	940	50	81	38	26.7
Block 2	38	28	30.5	930	50	81	30.7	22.7
TOTALS	85	61					68.7	49.4

Percent Difference 11%

TABLE 5 Confined Core Model

Lease No.	Resources in Mining Zone Tons x 10^7	Barrels x 10^7	Grade	Overburden	Mining Interval	Recovery %	Recoverable Resources Tons x 10^7	BBLs x 10^7
Utah Offered Lands								
ML-20732 20740	19	13.6	30	2025	60	50.4	9.6	6.9
20759	9.5	6.5	29	1530	50	58.5	5.6	3.8
20760	9.2	7.2	33	1855	50	54.8	5.0	3.9
20761	11.5	7.4	27	2260	60	48.8	5.6	3.6
20762	11.5	7.5	27	2510	60	47.1	5.4	3.5
20763	11.2	8.3	31	2770	60	45.4	5.1	3.8
20764	11.3	8.1	30	2765	60	45.4	5.1	3.7
20765	16	9.9	26	2790	60	45.4	7.3	4.5
20758	4.1	2.8	29	950	50	68	2.8	1.9
20784	10.8	8.0	31	2030	60	50.4	5.4	4.0
TOTALS	114.1	79.2	29.2				56.9	39.6
Selected Federal Lands								
Block 1	47	33	29.5	940	50	68	32	22.4
Block 2	38	28	30.5	930	50	68	25.8	19.0
TOTALS	85	61	30.1				57.8	41.4

Percent Difference 4%

recovery. The effect of the average greater depth to the mining zone under offered lands on mining costs, profitability, or lease royalities was not evaluated in this analysis.

VII. Processing

While a variety of oil shale retorting and upgrading processes are available, similar processes were assumed to be available for offered and selected lands.

VIII. Summary

In-place resources on the offered state lands are 1,330 x 10^6 BBL of oil, compared to 848 x 10^6 BBL of oil on selected Federal lands. Three different techniques were used to prepare mine designs and estimate recoverable resources in the Mahogany Zone. Using the preferred direct stress method, the offered lands contain 424 x 10^6 BBLs of oil, compared to 457 x 10^6 BBL in the selected Federal lands, a 7% difference. This difference probably lies within the error limits of the variables used to calculate the estimates.

The approach used in this report to design the mine and estimate the recoverable resources on offered and selected lands recognizes the effect of depth, rock strength, and stratigraphic controls on resource recovery. Estimates of the effect of the difference in depth to the mining zone between the offered and selected lands on mining costs, profitability, or lease royalties are beyond the scope of this analysis.

APPENDIX

Justification for Selection of Procedures and Parameters

A. Oil Shale Yield (gals/ton) based on geophysical logs

The lands offered by Quintana Minerals Corporation are spread over several townships in the Uinta Basin. Most drill holes adjacent to the offered lands were not cored or sampled for oil shales. Fischer assays are not available for the proposed mining interval. Density or sonic geophysical logs were used to estimate the oil yield from the proposed mining zones. Two lines of evidence suggest this is a valid technique which produces estimates of oil shale yield (gals/ton) which approximate the yields from Fischer assays.

1. Quintana prepared regression models for oil shale yield using density (gm/cc) or sonic (transit time) measurements as independent variables. Its formulae are attached; correlation coefficients (R) exceed 0.99.

2. A blind experiment was conducted. Quintana was furnished copies of sonic and density logs from holes in Utah where detailed Fisher assays were available to the government. Results are summarized below:

Drill Hole	Interval (ft)		Geophysical Log	Fischer Assay
#1	685-728	43'	32 gal/T	31.5 gal/T
#2	948-972	25'	36 gal/T	37 gal/T
#3	802-830	28'	33 gal/T	28 gal/T

Histograms were prepared for each pair of holes and are attached to the Appendix. After examining these histograms and those prepared for the cross-sections (Plates 1-3), several generalizations are possible.

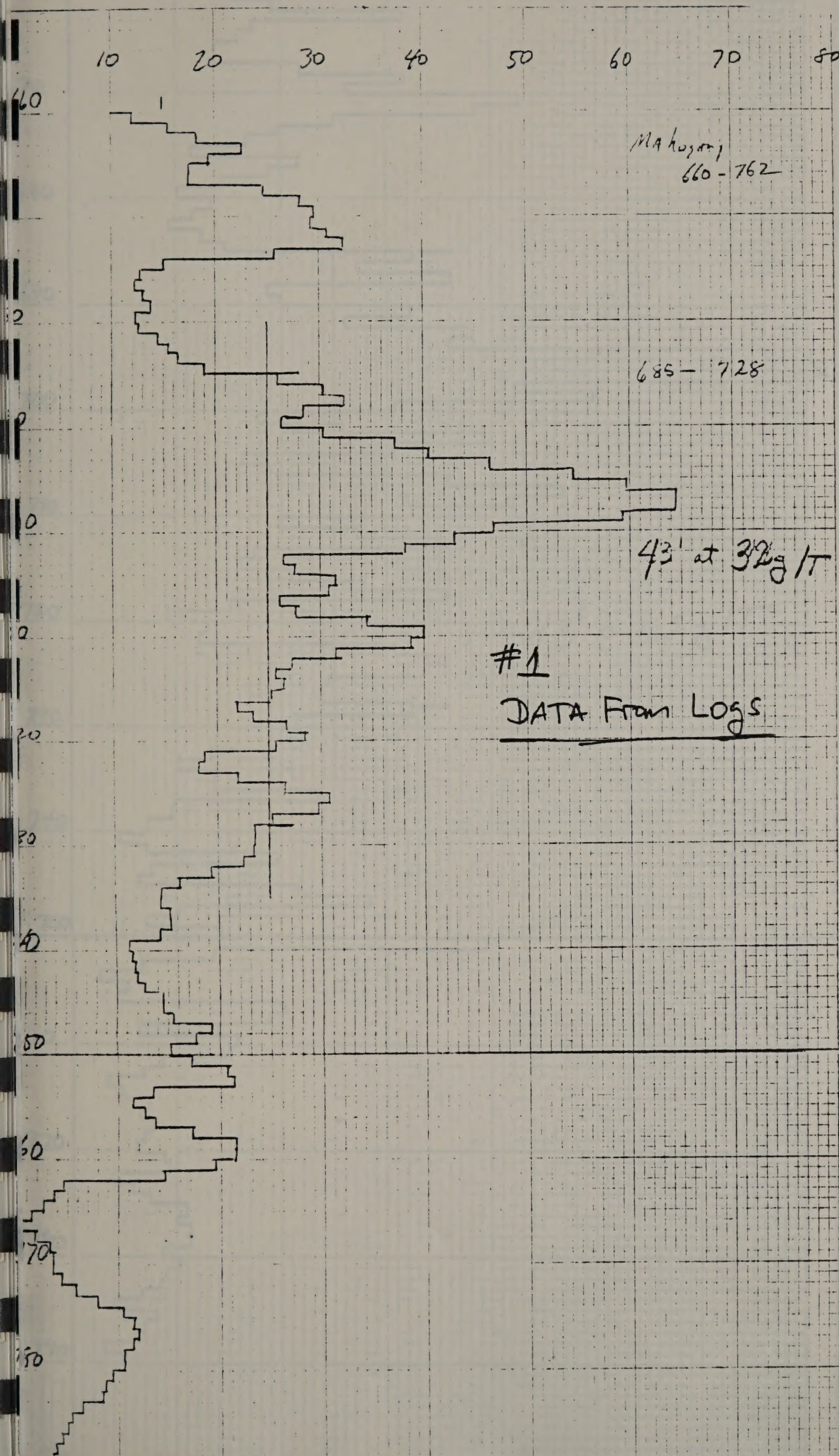
a) Oil yield histograms derived from geophysical logs show less variation in yield than those based on Fischer assays.

b) Maximum yields based on geophysical logs are less than those from Fischer assays.

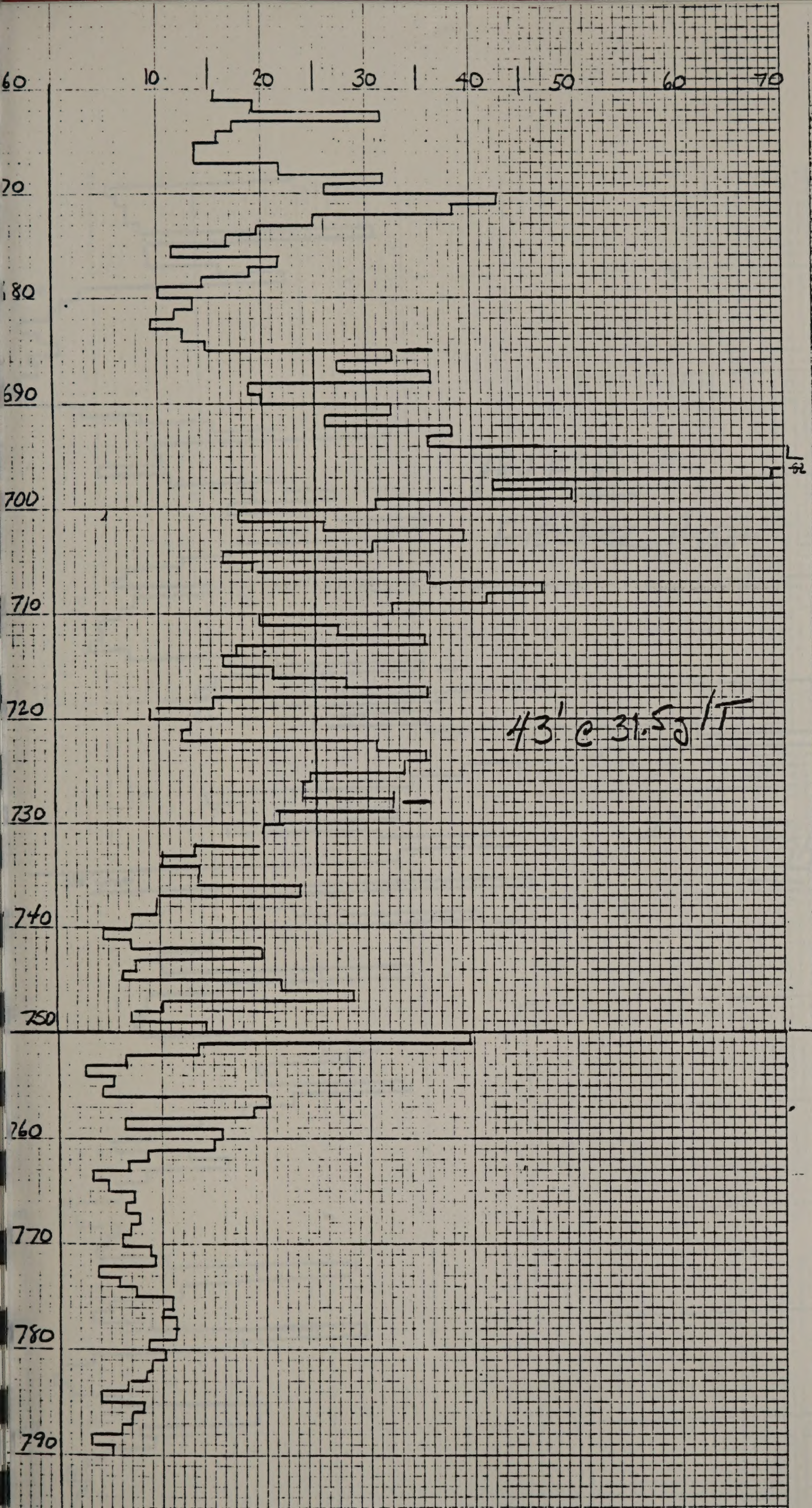
c) The general shape of both types of histograms are similar; correlation between holes across the basin is relatively easy.

d) Shale oil yields averaging over 50-60 feet are essentially equivalent, within the error limits of both geophysical logs and Fischer assays. The small variation in shale oil yield across the basin further suggests the validity of using geophysical logs to estimate yield when Fischer assays are unavailable.

In addition, the Oil Shale Office solicited comments from the Sedimentary Minerals Resources Branch, Office of Energy Resources, Geologic Division, U.S. Geological Survey. Based on her experience, Janet Pitman reported excellent correlation between sonic or density logs and Fischer assays for core holes in the Uinta Basin. In fact, she reported that this technique was first



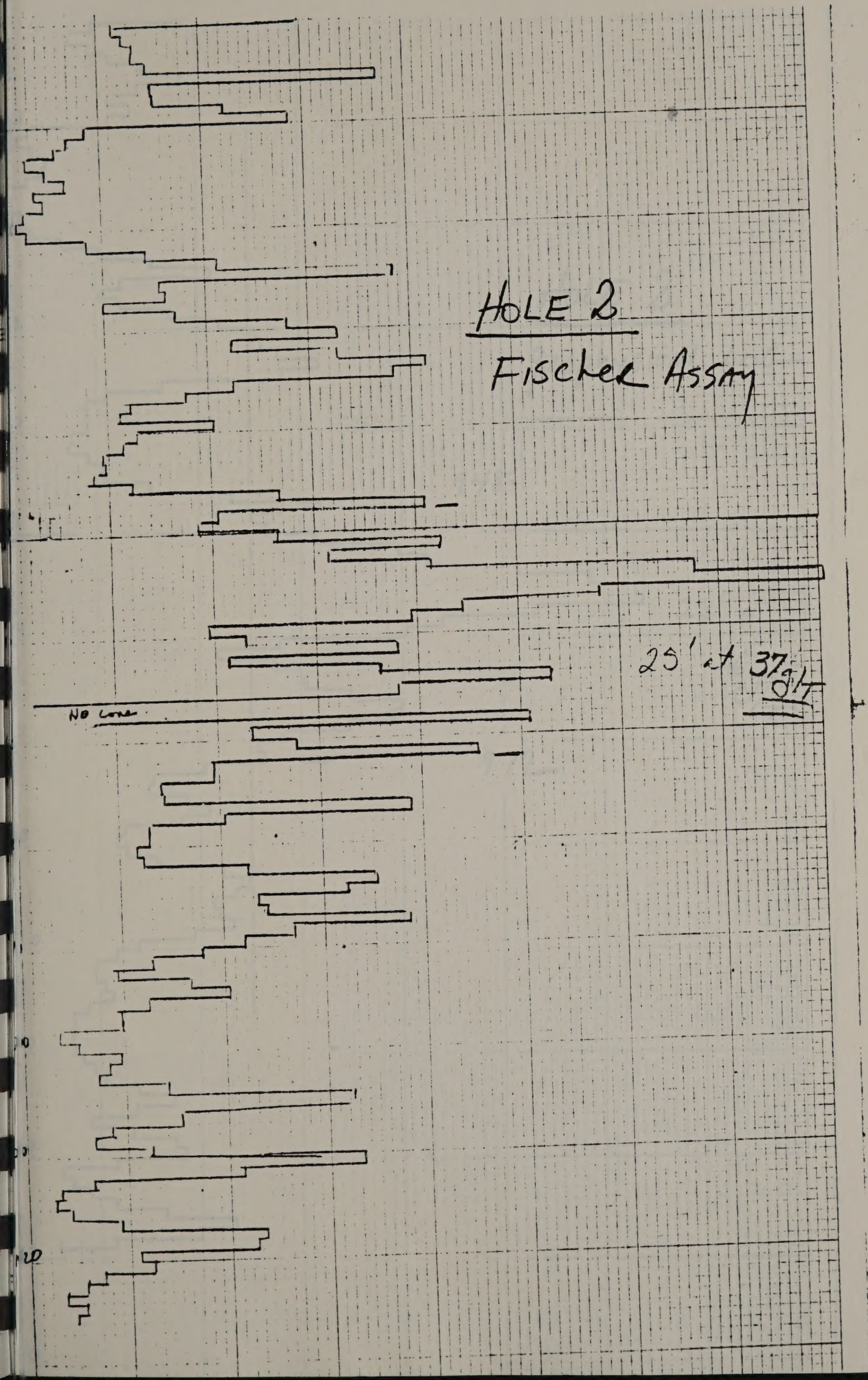
10 20 30 40 50 60 70 80
660
Mahogany
660 - 762
685 - 728
43' at 32g/T
#1
DATA From Logs

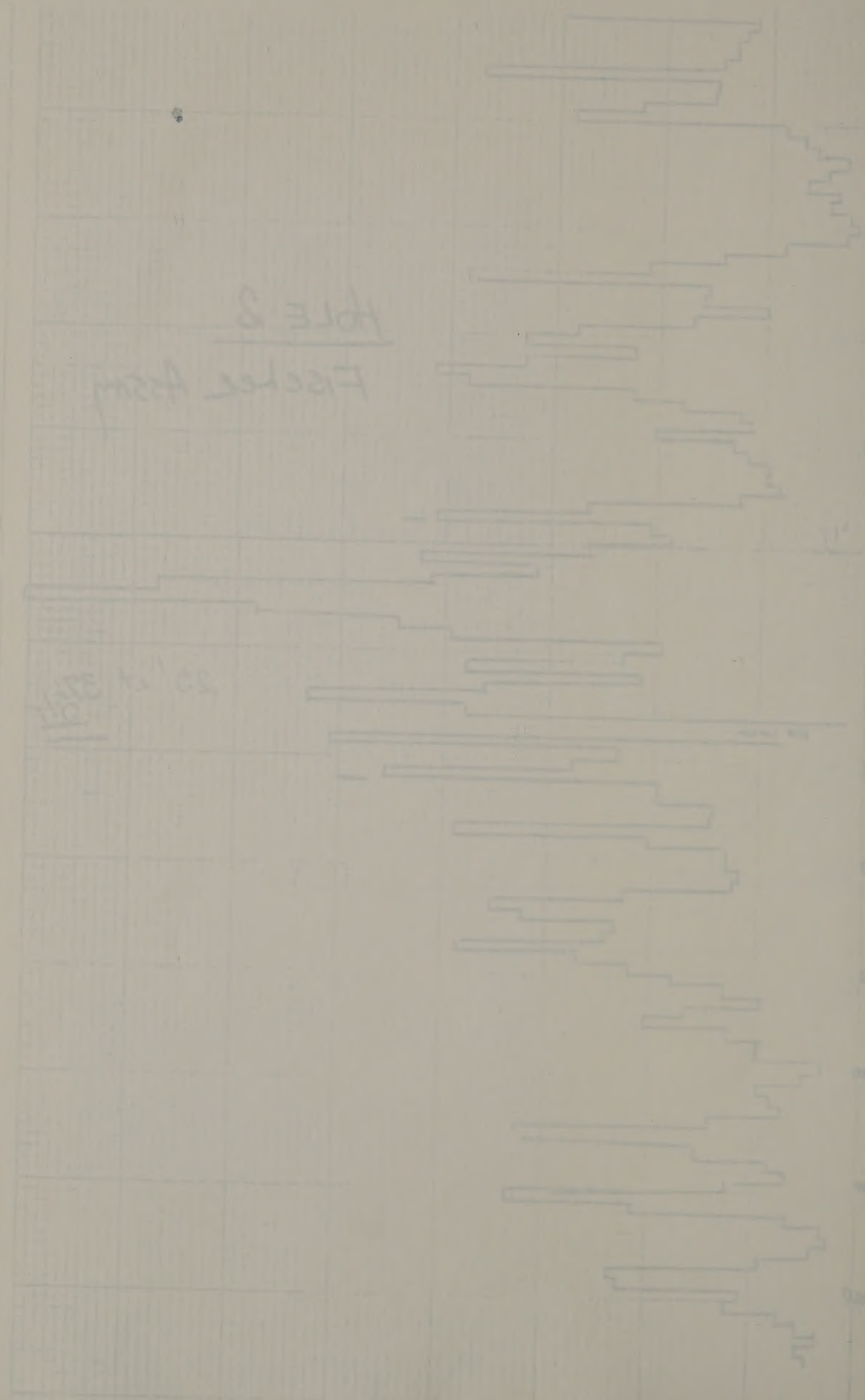


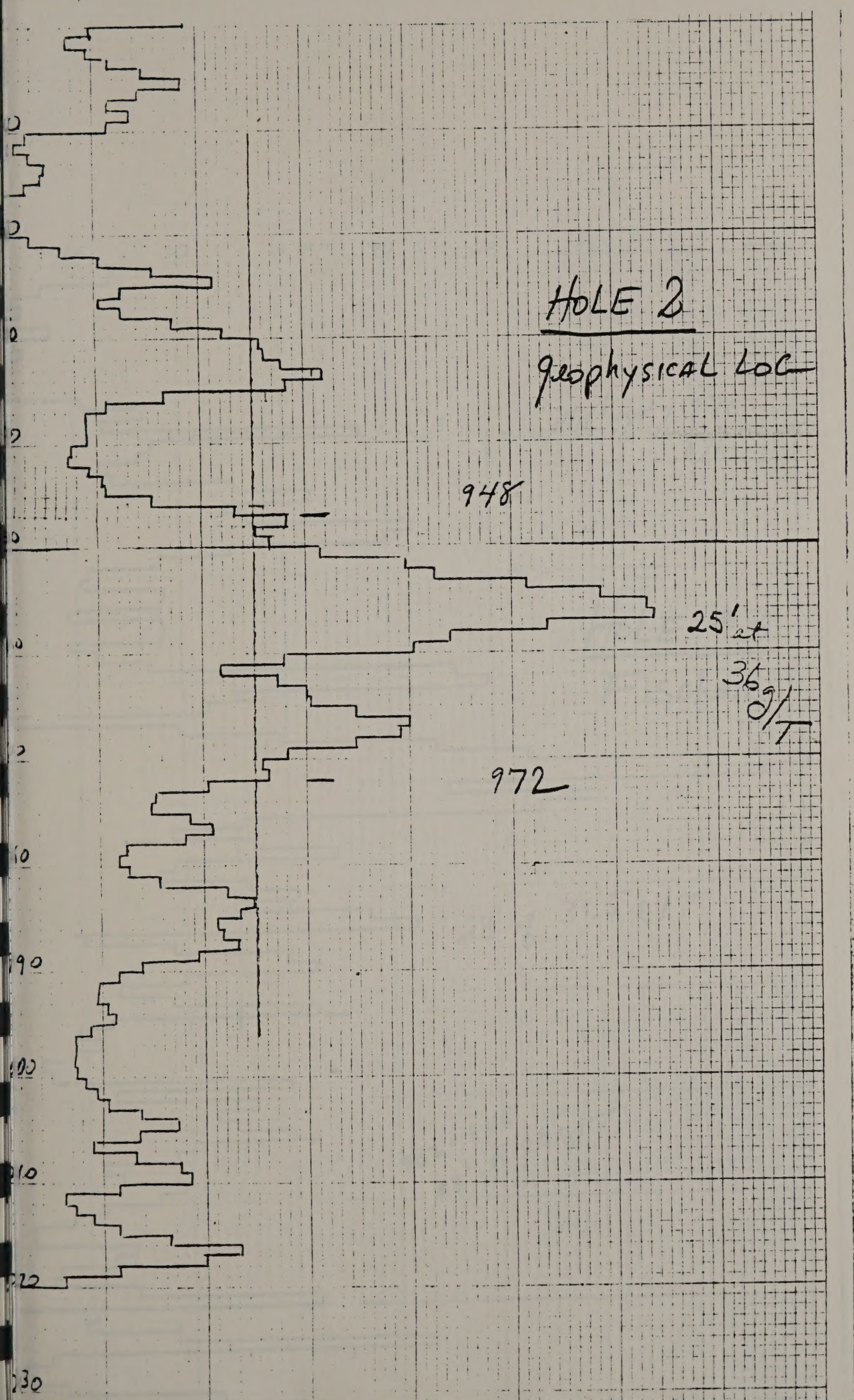
DRILL HOLE

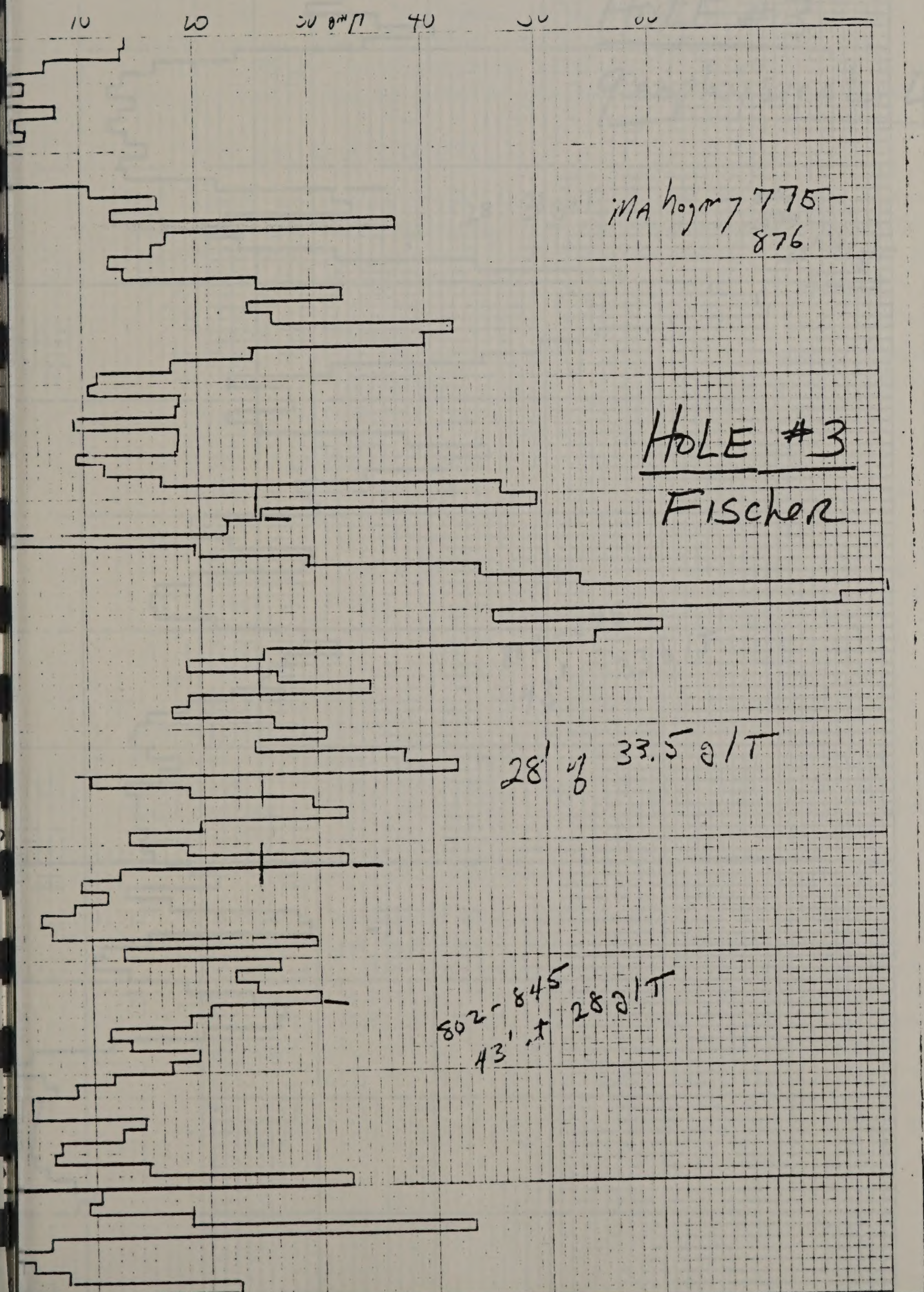
#1

Fischer
Assay

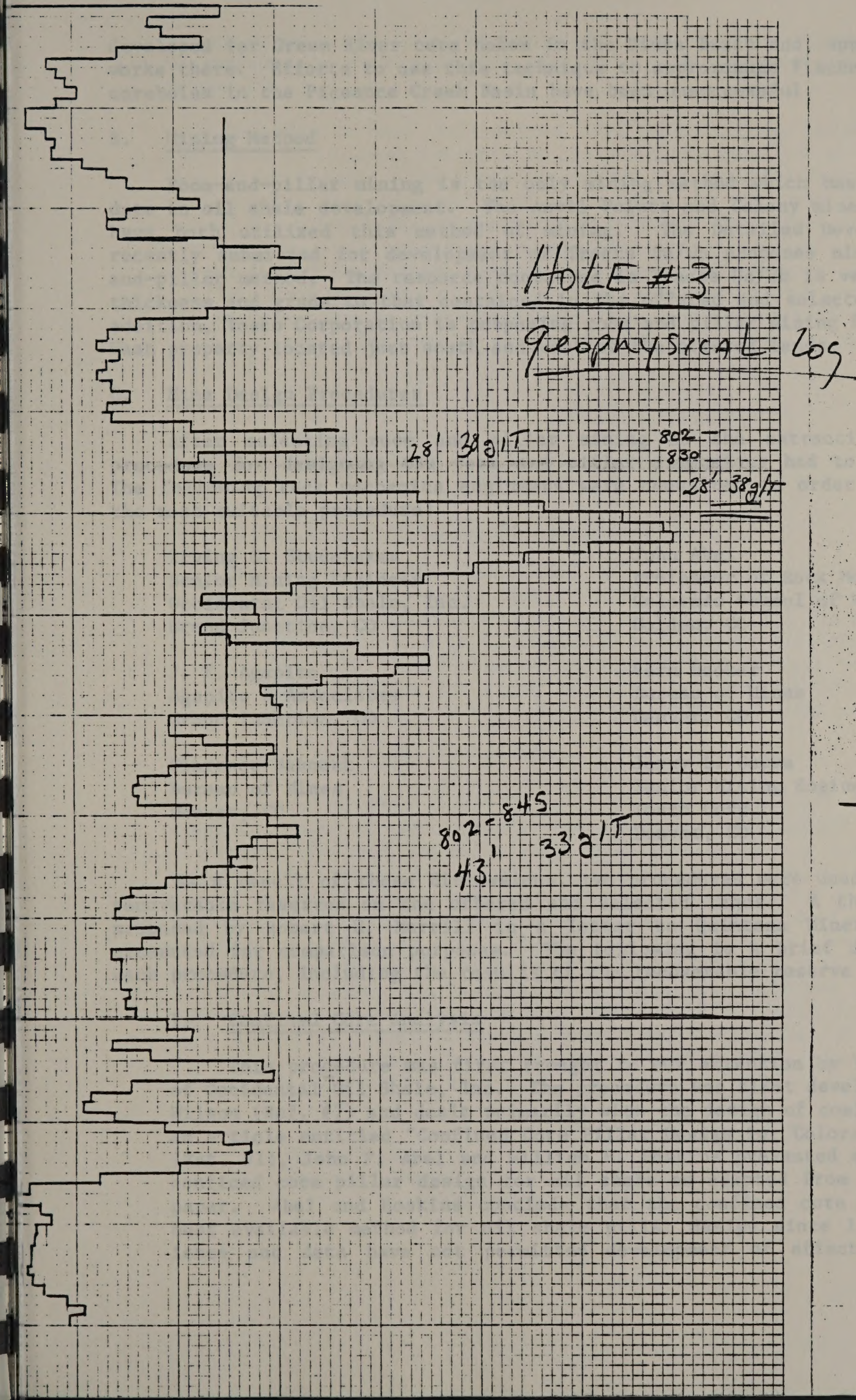

HOLE 2
Fischer Assay
25' at 37g/t
NO Core




HOLE 2
geophysical LOG
948
25' at
36 g/T
972



10
20
40
Mahogany 775-876
HOLE #3
FISCHER
28' of 33.5 g/T
802-845
43' of 28 g/T



862
852

4823.2
3291.5

30,634

developed for Green River core holes in the Uinta Basin and, apparently, only works there. Efforts to use this technique to approximate Fischer assays from coreholes in the Piceance Creek Basin have been unsuccessful.

B. Mining Method

Room-and-pillar mining is the only mining method which has been used to date in oil shale development. The Anvil Points and Colony mines in Colorado have both utilized this method of mining. The Detailed Development Plan recently submitted for development of Tracts Ua/Ub proposes mining by room-and-pillar method. The resource contained in Tracts Ua/Ub is very similar in thickness and grade to that contained in the offered and selected lands. In addition, Tosco Corporation is proposing room and pillar mining for their Sand Wash property located just south and west of the offered lands.

C. Mine Design Procedures

After selecting room and pillar mining as the extraction method, a procedure for designing the room and pillar dimensions had to be selected. The following rock mechanics engineers were consulted in order to determine the most suitable procedure:

Irving G. Studebaker
Senior Mining Engineer
Occidental Oil Shale, Inc.
Grand Junction, CO

John Abel
Professor of Rock Mechanics
Colorado School of Mines
Golden, CO

J. F. Agapito
Agapito & Associates
Grand Junction, CO

Vern Hooker
Bureau of Mines
Denver, CO

Clarence Babcock
Bureau of Mines
Denver, CO

Jerry L. Gupka
Senior Mining Engineer
Tosco Corp.
Denver, CO

As a result of these discussions, two procedures were used to calculate recoverable reserves on the offered and selected lands. A third procedure proposed by Robert H. Merrill in a letter to Quintana Minerals Corp. is presented for comparison purposes. The following is a brief description of each procedure, including the results of the recoverable reserve calculations.

1. Confined Core Analysis

This procedure was first brought to our attention by Irv Studebaker of Occidental Oil Shale, Inc. The procedure was first developed by A. H. Wilson (Ref. #7) and dealt primarily with the design of coal pillars. In an article entitled "Confined Core Pillar Design for Colorado Oil Shale" (Ref. #1), John F. Abel and William H. Hoskins presented a method using confined core pillar design for oil shale as adapted from Wilson's 1972 paper. Abel and Hoskins conclude that the confined core method is the best available method for oil shale pillar design since lack of experience and data have not permitted development of effective empirical

pillar design. Mr. Abel is presently teaching the confined core method to students in rock mechanics classes at the Colorado School of Mines, Golden, CO.

In order to use the confined core method, it is necessary to know the angle of internal friction of the rock, the cohesion of the rock, and the pillar height. Conservative values for angle of internal friction and cohesion were selected from the article by Abel and Hoskins. Once values for these three parameters are selected the design problem becomes a trial and error procedure to determine pillar dimensions necessary to accommodate the predicted loading for a selected factor of safety (F.S. = 1.2 for this analysis). If the room span calculated for the assumed pillar dimensions is deemed adequate, then the recovery at that depth can be calculated. The results of the analysis using this procedure are as follows:

	Recoverable Barrels
Offered Lands	39.6×10^7
Selected Lands	41.4×10^7

Difference = 4%

2. Direct Stress Analysis with Correction for W/H

This procedure was recommended by Vern Hooker and Clarence Babcock with the Bureau of Mines, Denver, CO. The parameters used in this procedure are the compressive strength of the rock and the pillar height. A factor of safety of 2 to 4 is usually recommended for this analysis and 2.5 was selected. A compressive strength of 11,000 psi was used for a pillar having a width to height ratio of 1. The following formula was used to adjust the pillar strength as the width to height ratio changed:

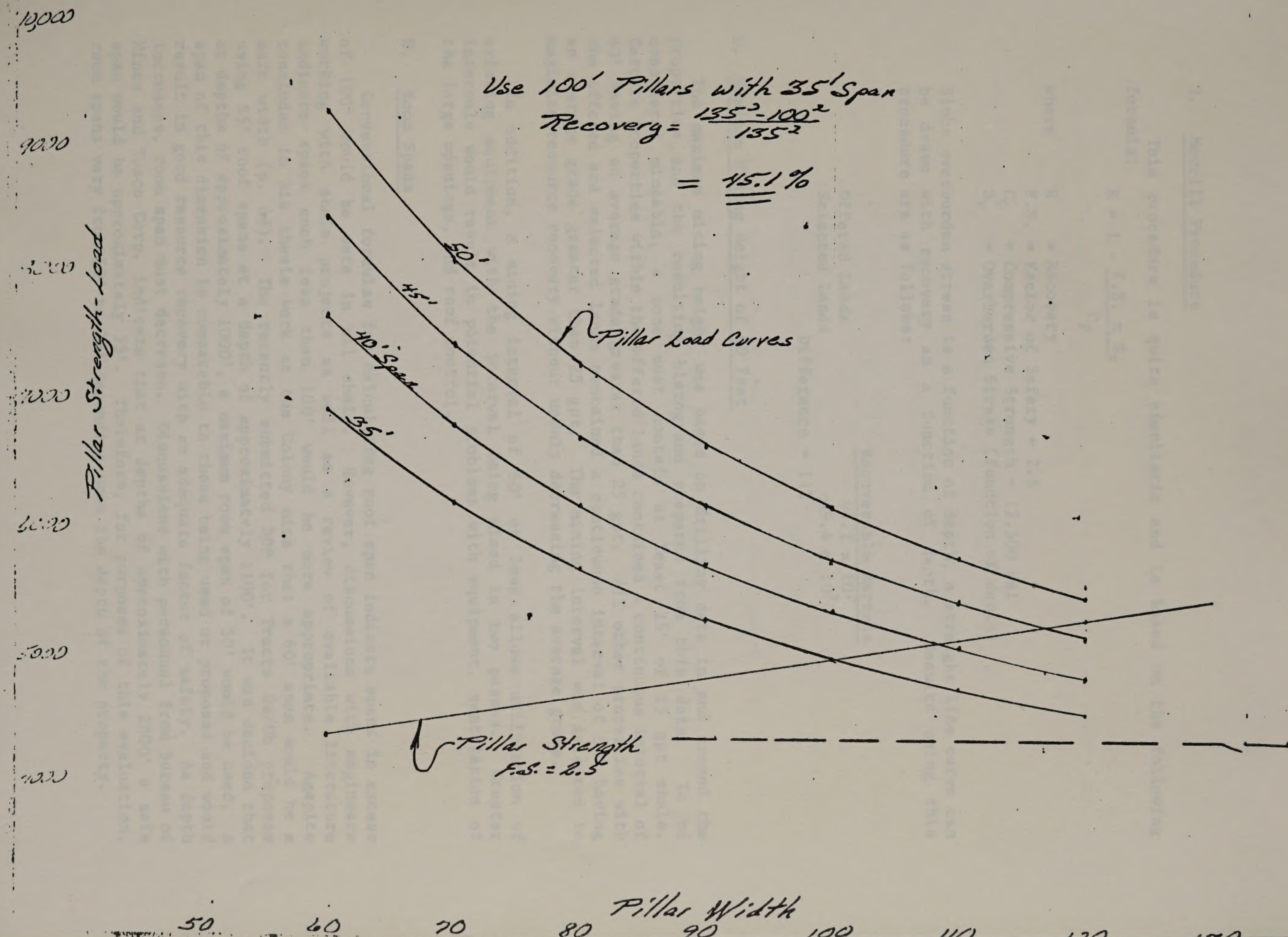
$$Gp = 11,000\ (.778 + .222\ W/H) \qquad \text{(Ref. 5)}$$

For purposes of this analysis, a series of curves were drawn for the specific depths of each property and specific mining height (see attached figure). For room spans ranging from 35' to 50', a curve was drawn relating the pillar load (psi) as a function of the pillar width. A second straight line curve was drawn based on pillar strength as a function of the width to height ratio (see formula listed earlier) using a factor of safety of 2.5. The intersection of this line and the room span curve determine the proper pillar width and room span for that depth and mining height. The specific room spans were selected to coincide as closely as possible with the span used for that depth in the confined core analysis. Upon selecting room span and pillar dimensions, the recovery at that depth can once again be calculated. Results of these calculations are as follows:

	Recoverable Barrels
Offered Lands	42.4×10^7
Selected Lands	45.7×10^7

Difference = 7%

Mining Ht: 60'


Use 100' Pillars with 35' Span
Recovery = $\frac{135^2 - 100^2}{135^2}$
= 45.1%
Pillar Strength-Load
10,000
9000
8000
7000
6000
5000
4000
50'
45'
40' Span
35'
Pillar Load Curves
Pillar Strength
F.S. = 2.5
Pillar Width
50
60
70
80
90
100
110
120

3. Merrill Procedure

This procedure is quite simplistic and is based on the following formula:

$$R = 1 - \frac{F.S. \times S_v}{C_p}$$

where
R = Recovery
F.S. = Factor of Safety = 2.5
C_p = Compressive Strength - 12,500 psi
S_v = Overburden Stress (function of depth)

Since overburden stress is a function of depth, a straight line curve can be drawn with recovery as a function of depth. Results using this procedure are as follows:

	Recoverable Barrels
Offered Lands	44.1×10^7
Selected Lands	49.4×10^7
Difference = 11%	

D. Maximum Mining Height of 60 Feet

The maximum mining height was based on drilling data in and around the properties and the resulting histograms prepared from this data. To be considered mineable, a zone must contain at least 25' of 25 gpt shale. Certain properties within the offered lands contained a continuous interval of 60' having an average grade greater than 25 gpt. All other properties with the offered and selected lands contained a continuous interval of 50' having an average grade greater than 25 gpt. The mining interval was selected to maximize resource recovery without unduly decreasing the average grade.

In addition, a mining interval of 60' or less allows utilization of existing equipment with the interval being mined in two passes. Greater intervals would result in potential problems with equipment, ventilation of the large openings, and roof control.

E. Room Spans

Conventional formulas for calculating roof span indicate spans in excess of 100' would be safe in oil shale. However, discussions with engineers working with shale projects as well as a review of available literature indicate spans much less than 100' would be more appropriate. Agapito concluded in his thesis work at the Colony mine that a 60' span would be a safe width (p. 43). The recently submitted DDP for Tracts Ua/Ub proposes using 55' roof spans at a depth of approximately 1100'. It was decided that at depths of approximately 1000', a maximum room span of 50' would be used. A span of this dimension is comparable to those being used or proposed and would result in good resource recovery with an adequate factor of safety. As depth increases, room span must decrease. Discussions with personnel from Bureau of Mines and Tosco Corp. indicate that at depths of approximately 2800' a safe span would be approximately 35'. Therefore, for purposes of this evaluation, room spans vary from 50' to 35' depending upon the depth of the property.

<u>References</u>

1. Abel, John F., and Hoskins, William N., 1976, Confined core pillar design for Colorado oil shale: Proceedings of the Ninth Oil Shale Symposium, v. 71, no. 4, p. 287-307.

2. Agapito, J. F., 1974, Rock mechanics applications to the design of oil shale pillars: Mining Engineering, v. 26, no. 5, p. 20-25.

3. Agapito, J. F., 1974, Plant and mine studies, Parachute Creek, Colorado: Ph.D. Thesis prepared for the Colorado School of Mines, p. 1-195.

4. Babcock, C., Morgan, T., and Haramy, K., 198__, Review of pillar design equations including the effects of restraint, p. 23-33.

5. Obert, L., Duvall, W., and Merrill, R., 1060, Design of underground openings in competent rock: Bulletin 587, USBM, 36 p.

6. White River Shale Project, 1981, Detailed development plan for Tracts Ua/Ub, v. 1, p. 3-42 to 3-59.

7. Wilson, A. H., 1972, Research into the determination of pillar size, Part 1, A hypothesis concerning pillar stability: Mining Engineer, v. 131, no. 4, p. 409-417.

YIELD EQUATIONS

<u>Big Three through Mahongany</u>

Density Log:

$$\text{Yield} = 24.9568 * \text{Density}^2 - 185.1055 * \text{Density} + 316.2121$$

Sonic Log:

$$\text{Yield} = 0.0031168 * \text{Sonic}^2 - 6.0316$$

Density computed from Sonic:

$$\text{Density} = 2.9619 - 0.0057 * \text{Sonic} - 0.132\text{E-}4 * \text{Sonic}^2$$

<u>B Groove through R-4</u>

Density Log:

$$\text{Yield} = 174.23 - 67.469 * \text{Density}$$

Sonic Log:

$$\text{Yield} = 0.5286 * \text{Sonic} - 32.878$$

Density computed from Sonic:

$$\text{Density} = 3.0697 - 0.00783 * \text{Sonic}$$

TABLE 1

PROCEDURES USED FOR DEVELOPMENT OF YIELD EQUATIONS

1. Sonic and Density logs were digitizied using 0.5 foot sample increment and input into PETROS system.

2. Fischer assay core data was input from tabulations. Each one foot sample was repeated to produce 0.5 foot sample.

3. Plots of all digitized data were made to verify accuracy of digitizing and to determine depth discrepancies.

4. The density log was depth corrected for best correlation with the sonic log, then both logs were block shifted to match the core data. The following log shifts were used for initial correlation:

WELL	SHIFT
1	Down 2.5 ft
2	Down 6.0 ft
3	Up 2.0 ft
5	Up 2.5 ft
125	No Shift

5. Where possible no depth shifts were made to the core data. Wells 125 and 5 had zones where lack of correlation with logs indicated problems with core depths. On well 125 the interval 2316.5 through 2374 was shifted up 5.5 ft. The resulting gap from 2369 through 2374.5 was filled by interpolation. As noted above, no block shift of the logs was done for well 125. The sonic log was approximately on depth with the core from 2000 to 2300 ft. Near the bottom of the log there was as much as 3 ft. of depth offset.

   The following three changes were made to well 5 core data:

   1. The interval 1775-1794 was swapped with 1795-1814.

   2. The interval 1815-1834 was swapped with 1835-1854.

   3. The interval 1855-1892 was turned upside down.

6. The core data was filtered with a smoothing function designed to match the vertical averaging of the logs.

7. Interior depth shifts were made as required to maximize log-core correlation. These shifts were generally 0.5 to 1.0 foot changes over short intervals.

8. Regression and crossplot analysis were made on individual wells and on a composite well created from cored intervals of Wells 3, 5, and 125. Wells 1 and 2, which were logged by Welex, have greatly different data values from the Schlumberger logs and were excluded from further analysis. The sonic log on Well 125 shows a zero offset of -8 microseconds/ft when compared with Wells 3 and 5. This was corrected by adding a constant of 8 to the entire sonic log. It appears that computation errors resulting from miscalibrations of this type can be minimized by forcing the average value in the A-Groove to be 63 for the sonic and 2.54 for the density. Zero offsets are common in both types of logs.

9. Correlations from the previous step were fairly good, however minor depth discrepancies caused enough scatter to mask the expected quadratic form of the yield equation. Attempts to refine the correlations did show a significant change in both the sonic and density relationships below the Mahogany. It was then decided that separate equations should be developed for the Big 3 through the Mahogany and for the B-Groove through the R-4.

10. Next a cummulative frequency approach was used in attempt to tighten the correlation. This technique is sometimes called a Holgate crossplot. The procedure is quite simple. First core-yield, density and sonic are independently sorted in the direction of increasing yield without regard to depth. Next, the sorted data is analyzed as though successive sample came from common depth points. Crossplots of these data are shown in Figures 1 through 4. Linear regression equations are shown on the plots.

11. Final regression equations are shown in Table 1. The quadratic equations for the upper interval significantly improve results in high yield zones. It is expected that the lower interval should also have a quadratic form. All data for the lower interval comes from Well 125 and no high yield zones are included. This makes it impossible to predict the amount of curvature which might occur.

12. The yield was then computed for both density and sonic data. Foot by foot comparison of computed vs. core yield is summarized in Table 2. The mean difference and standard deviation in each well is good for both sonic and density data. The Table suggests that the sonic computation is

possibly better than the density computation. I do not believe this to be true. While the sonic relationship is very good, local changes in log response may produce biased results. An example of this is the Stillwell interval in Well 5. The sonic calculation is 5 or 6 gal/ton too high, while the density values are very close to core yield. This does not appear to be a change in formation properties since both sonic and density calculations in this interval in Well 125 match each other and core data very well.

Comparison of Computed vs Core Yield

Density log computation

Well	Interval	Mean of Difference	Standard Deviation of Difference
3	2042 - 2095	2.01	3.32
5	1686 - 2050	0.54	2.75
125	2002 - 2354	-0.28	3.05
125	2355 - 2830	-0.60	3.47
125	2002 - 2830	-0.46	3.30

well 3
60 data
port

2 125
400 data
points

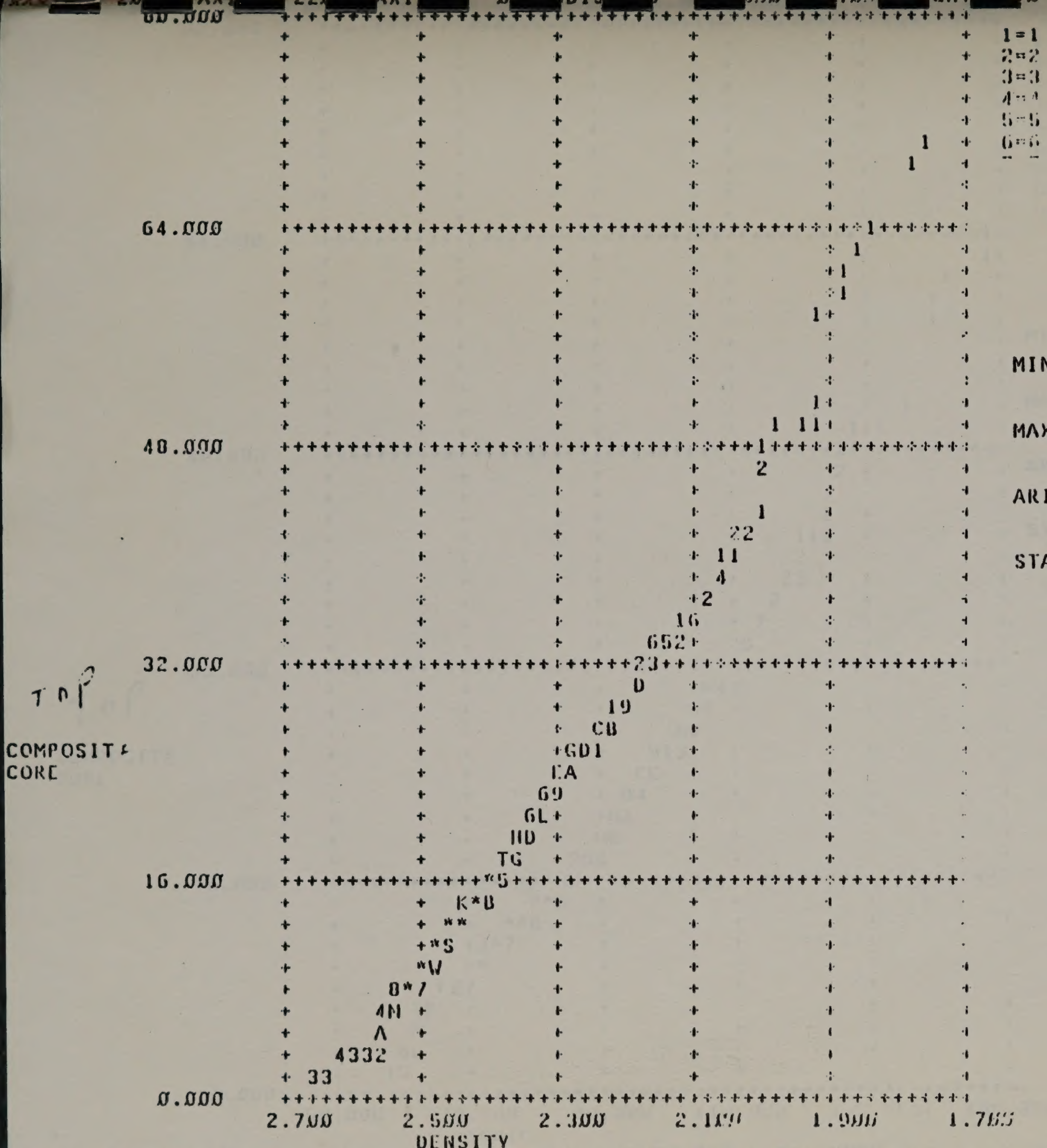
Sonic log computation

Well	Interval	Mean of Difference	Standard Deviation of Difference
3	2042 - 2095	~~-1.27~~	2.66
5	1686 - 2050	0.43	3.83
125	2002 - 2354	-0.29	4.43
125	2355 - 2830	-0.20	2.00
125	2002 - 2830	-0.23	3.26

Computed – fisher assay

John Ward Smith
EX1

TABLE 2



STATISTICAL ANALYSIS

	X	Y
MINIMUM:	1.7500	1.3900
MAXIMUM:	2.6610	70.310
ARITHMETIC AVERAGE:	2.3961	16.410
STANDARD DEVIATION:	0.13237	9.3594

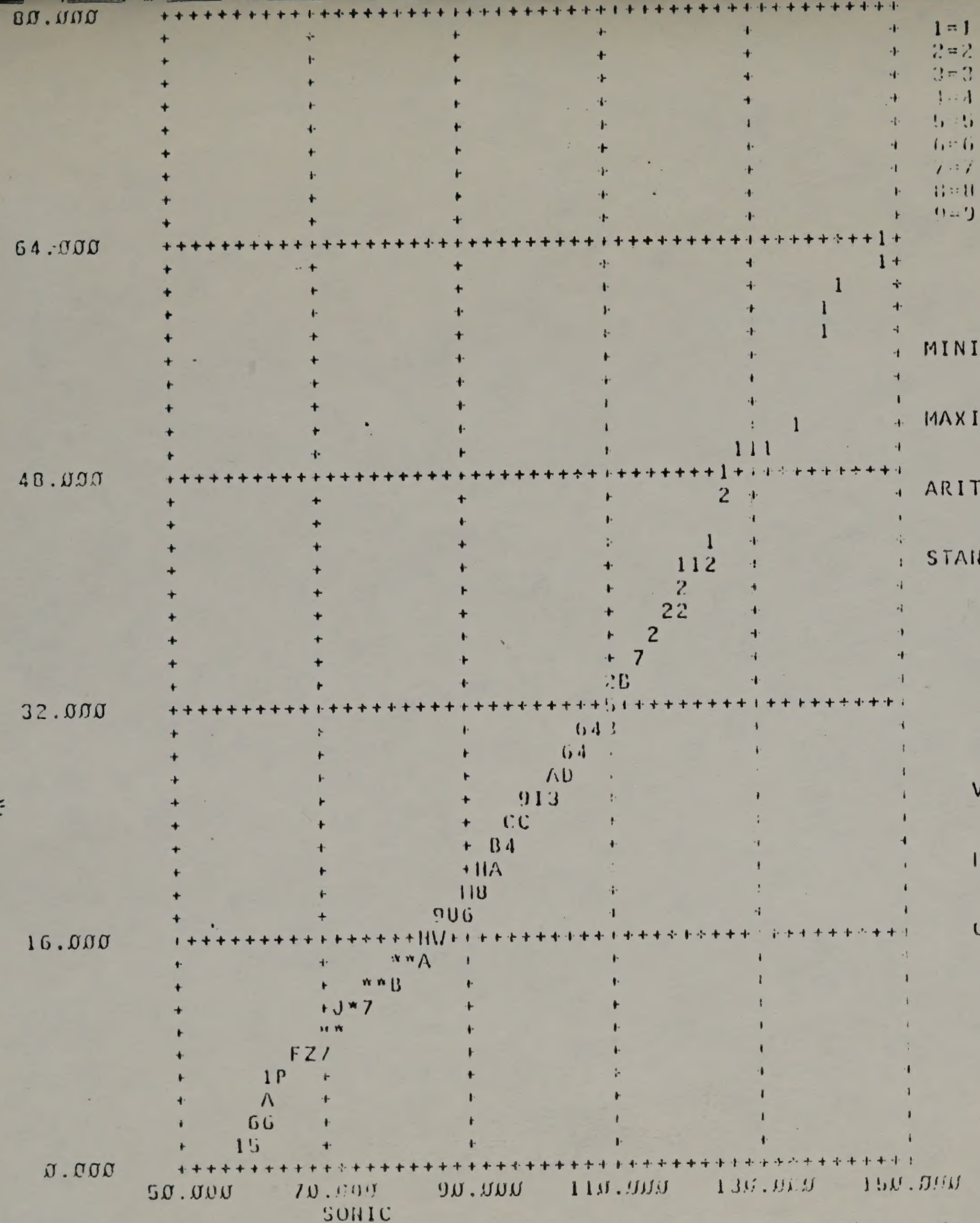
REGRESSIONAL ANALYSIS --

CORRELATION COEFFICIENT= 0.9945

VERTICAL	Y =	184.92	+ -70.327	* X
HORIZONTAL	Y =	186.76	+ -71.093	* X
ORTHOGONAL	Y =	186.76	+ -71.092	* X

AL SAMPLES PLOTTED = 700 NO. VALUES EQUAL TO -9999.0 : X= 0 Y= 0
OF VALUES OUTSIDE DISCRIMINATOR LIMITS: LOW A= NA HIGH A= NA LOW B= NA HIGH B= NA
VALUES OUTSIDE PLOT LIMITS: LEFT= 0 RIGHT= 0 TOP= 0 BOTTOM= 0

FIGURE 1



TOP

COMPOSITE
CORE

STATISTICAL ANALYSIS

	X	Y
MINIMUM:	58.700	1.3900
MAXIMUM:	148.80	63.350
ARITHMETIC AVERAGE:	83.257	16.274
STANDARD DEVIATION:	14.986	8.9757

REGRESSIONAL ANALYSIS --

CORRELATION COEFFICIENT= 0.99

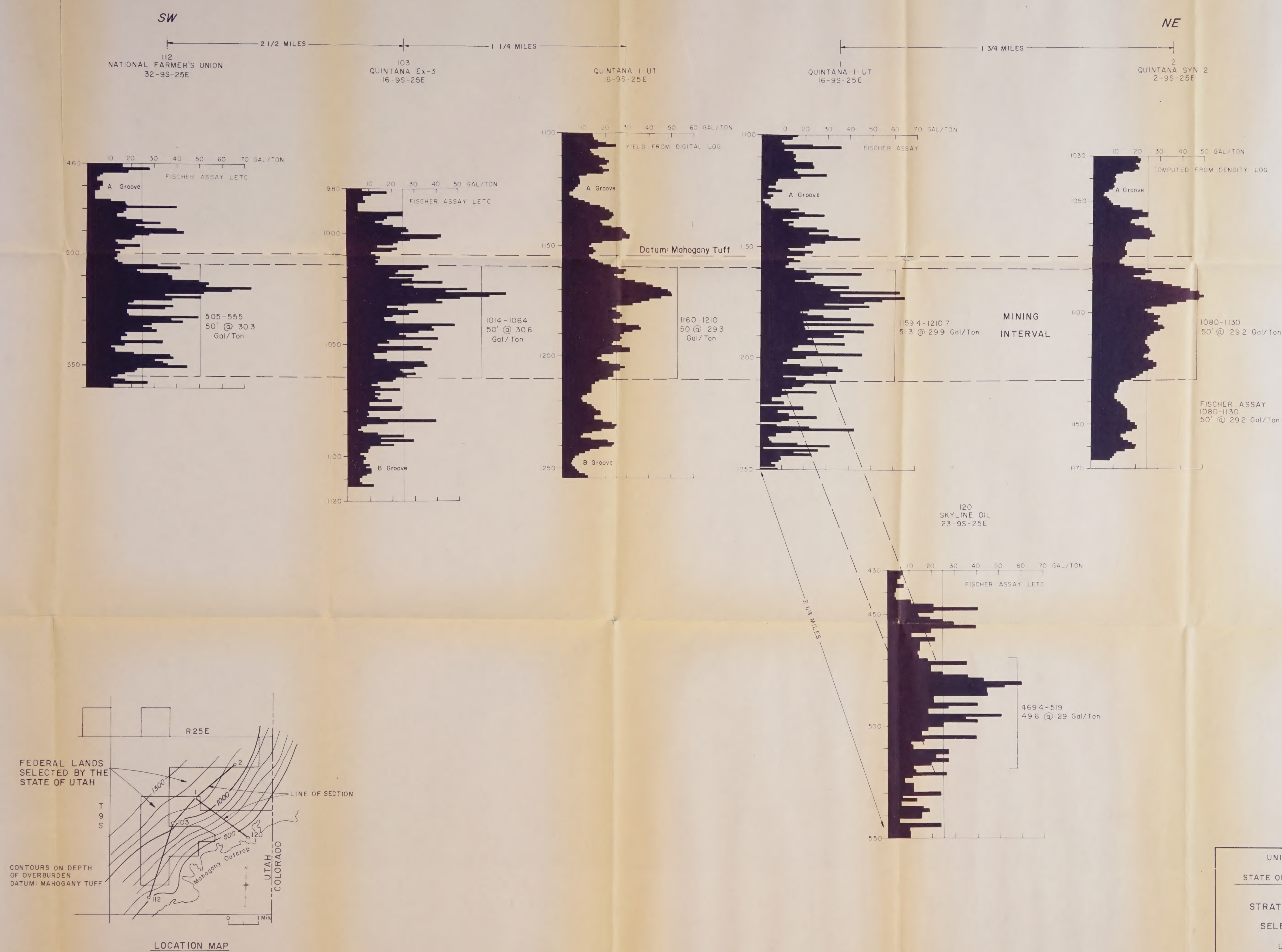
VERTICAL	Y = -33.094	+ 0.59296	* X
HORIZONTAL	Y = -34.096	+ 0.60499	* X
ORTHOGONAL	Y = -33.356	+ 0.59610	* X

TOTAL SAMPLES PLOTTED = 778 NO. VALUES EQUAL TO -9999.0 : X= 0 Y= 0

NO. OF VALUES OUTSIDE DISCRIMINATOR LIMITS: LOW A= NA HIGH A= NA LOW B= NA HIGH B= NA

NO.VALUES OUTSIDE PLOT LIMITS: LEFT= 0 RIGHT= 2 TOP= 0 BOTTOM= 0

FIGURE 2

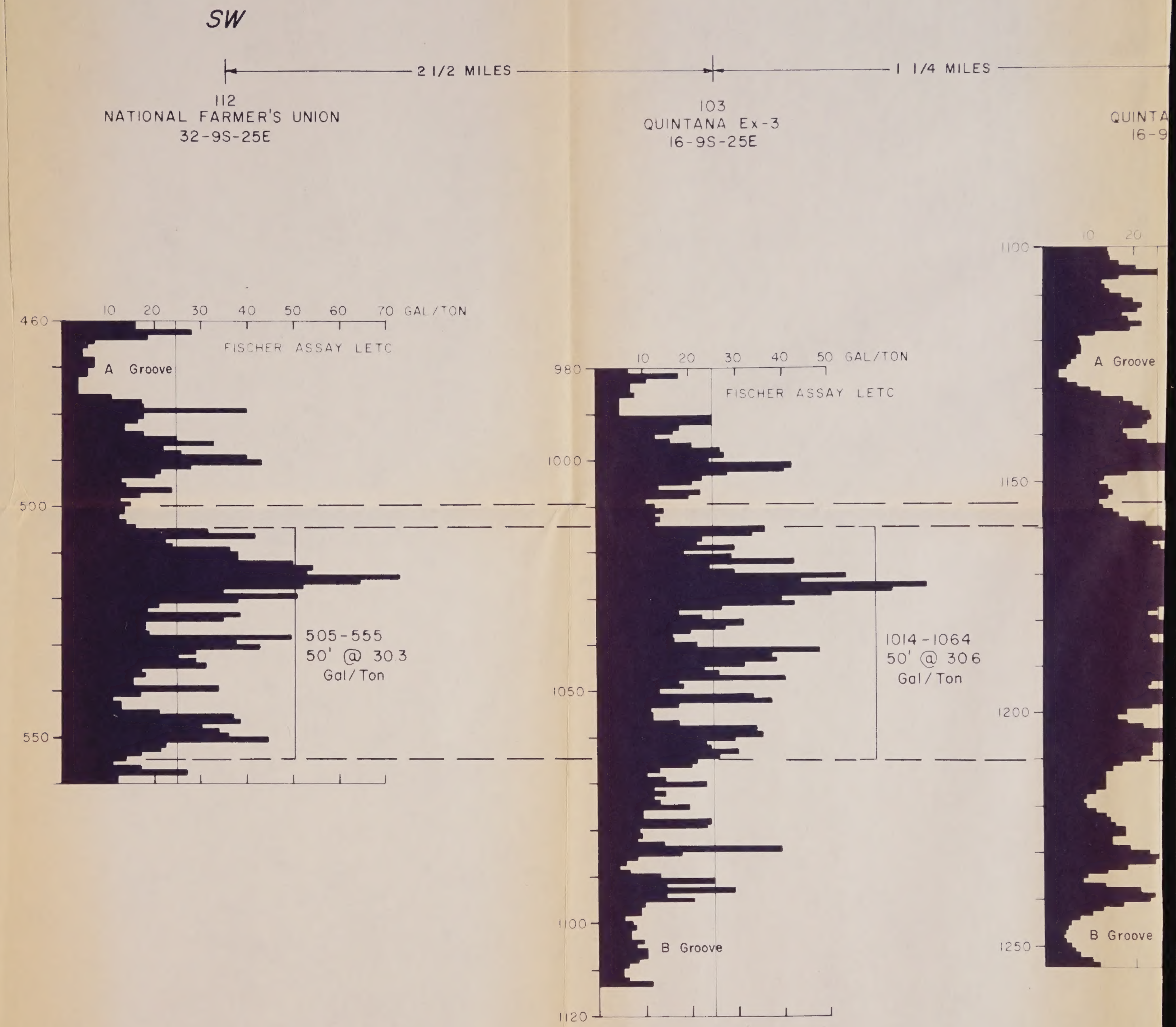


UNITED STATES OF AMERICA
AND
STATE OF UTAH PROPOSED EXCHANGE

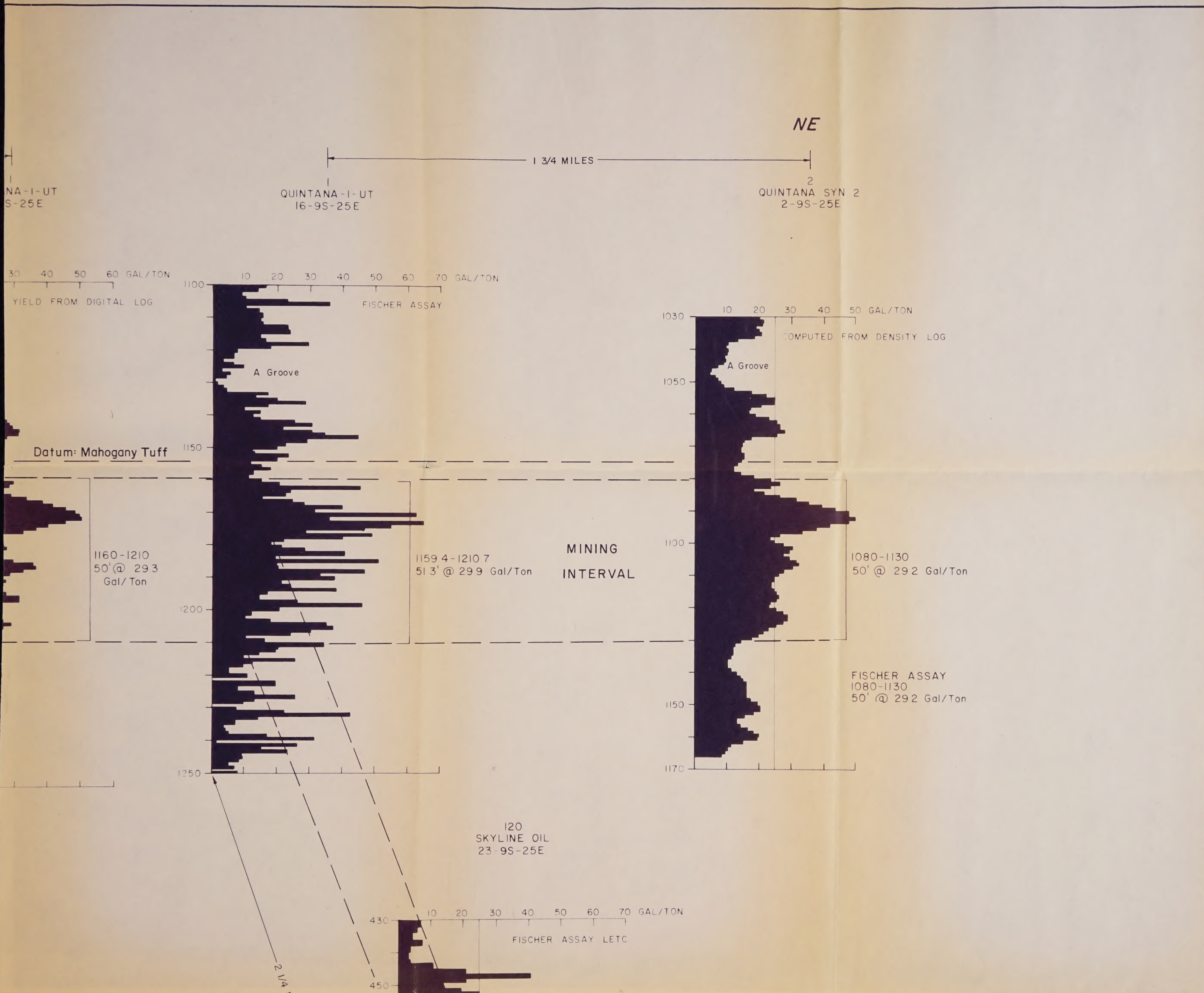
SW - NE
STRATIGRAPHIC CROSS SECTION
OF
SELECTED FEDERAL LANDS
T9S, R25E
UINTAH COUNTY, UTAH

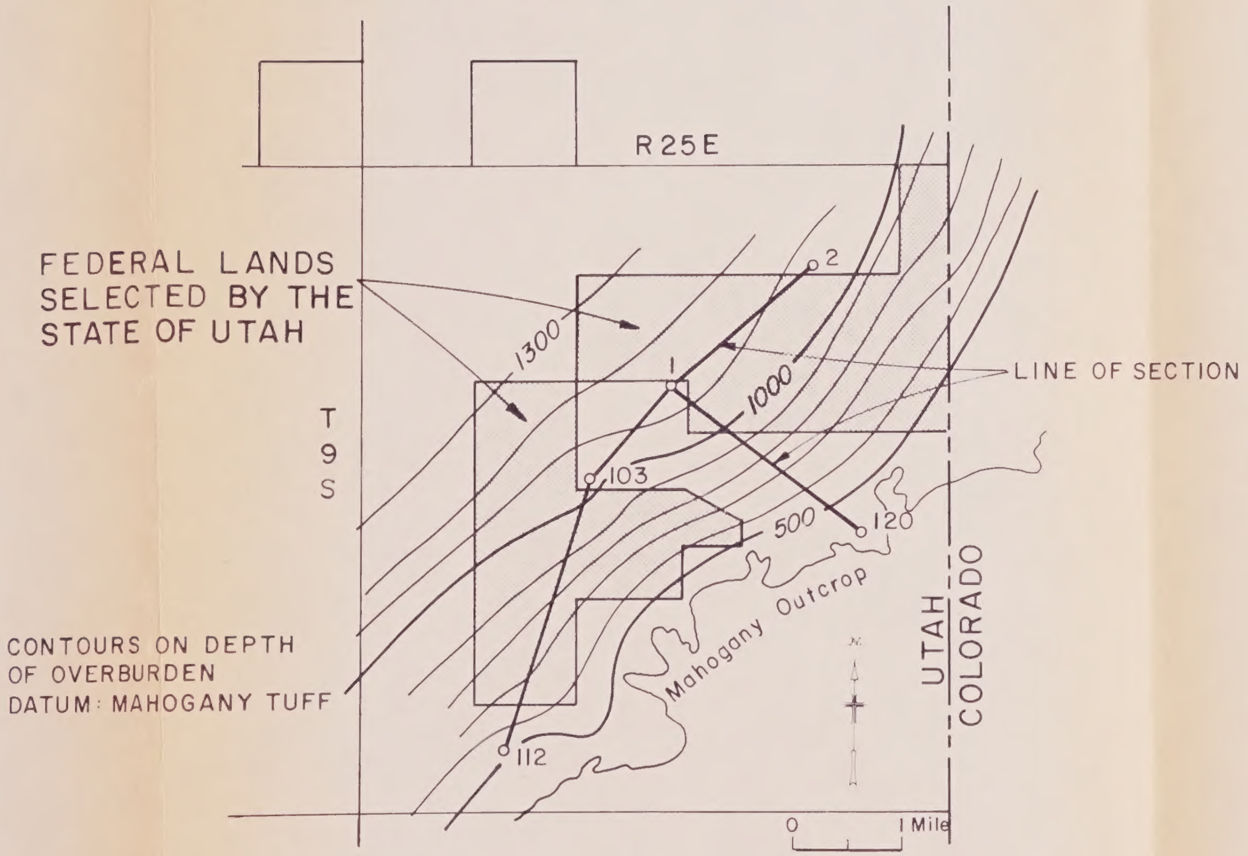
J. Rush
Nov. 1981

PLATE I

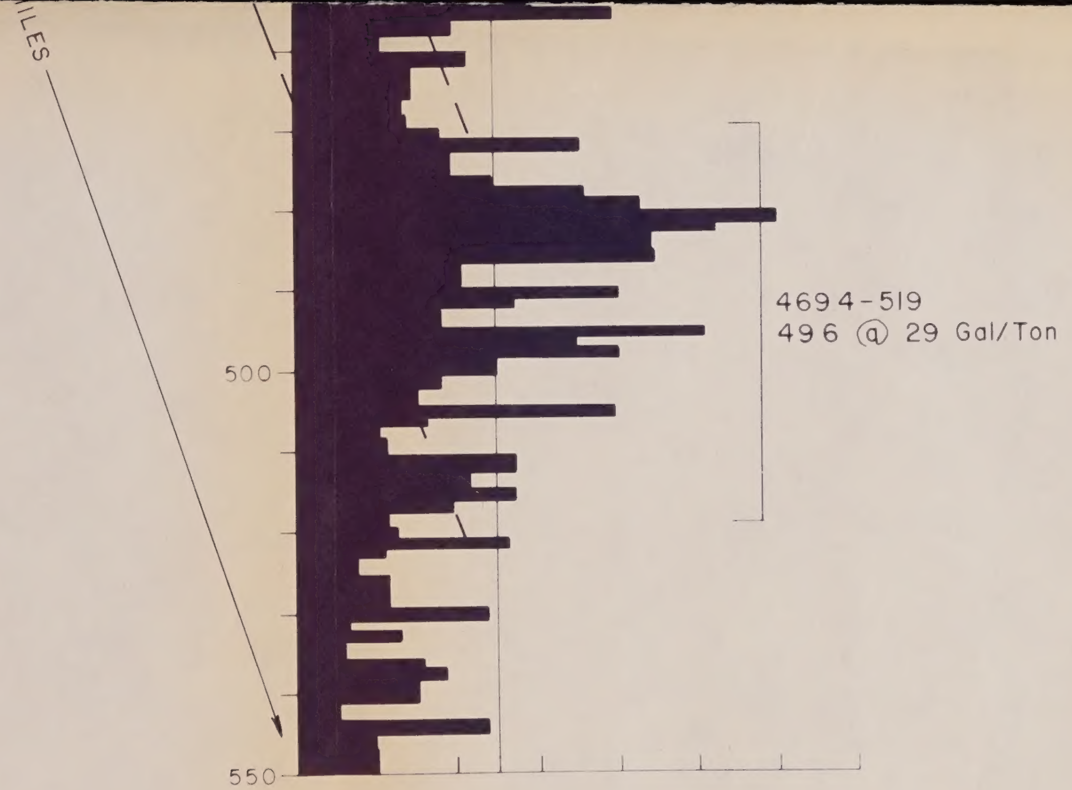


SW
2 1/2 MILES
1 1/4 MILES
112
NATIONAL FARMER'S UNION
32-9S-25E
103
QUINTANA Ex-3
16-9S-25E
QUINTA
16-9
10 20 30 40 50 60 70 GAL/TON
FISCHER ASSAY LETC
A Groove
460
500
550
505-555
50' @ 30.3
Gal/Ton
10 20 30 40 50 GAL/TON
FISCHER ASSAY LETC
980
1000
1050
1100
1120
1014-1064
50' @ 30.6
Gal/Ton
B Groove
1100
1150
1200
1250
10 20
A Groove
B Groove


NE
1 3/4 MILES
1
NA-1-UT
S-25E
1
QUINTANA-1-UT
16-9S-25E
2
QUINTANA SYN 2
2-9S-25E
30 40 50 60 GAL/TON
YIELD FROM DIGITAL LOG
10 20 30 40 50 60 70 GAL/TON
FISCHER ASSAY
10 20 30 40 50 GAL/TON
COMPUTED FROM DENSITY LOG
1100
1150
1200
1250
1030
1050
1100
1150
1170
A Groove
A Groove
Datum: Mahogany Tuff
1160-1210
50'@ 29.3
Gal/Ton
1159.4-1210.7
51.3' @ 29.9 Gal/Ton
MINING
INTERVAL
1080-1130
50' @ 29.2 Gal/Ton
FISCHER ASSAY
1080-1130
50' @ 29.2 Gal/Ton
120
SKYLINE OIL
23-9S-25E
10 20 30 40 50 60 70 GAL/TON
FISCHER ASSAY LETC
430
450
2 1/4 M



LOCATION MAP

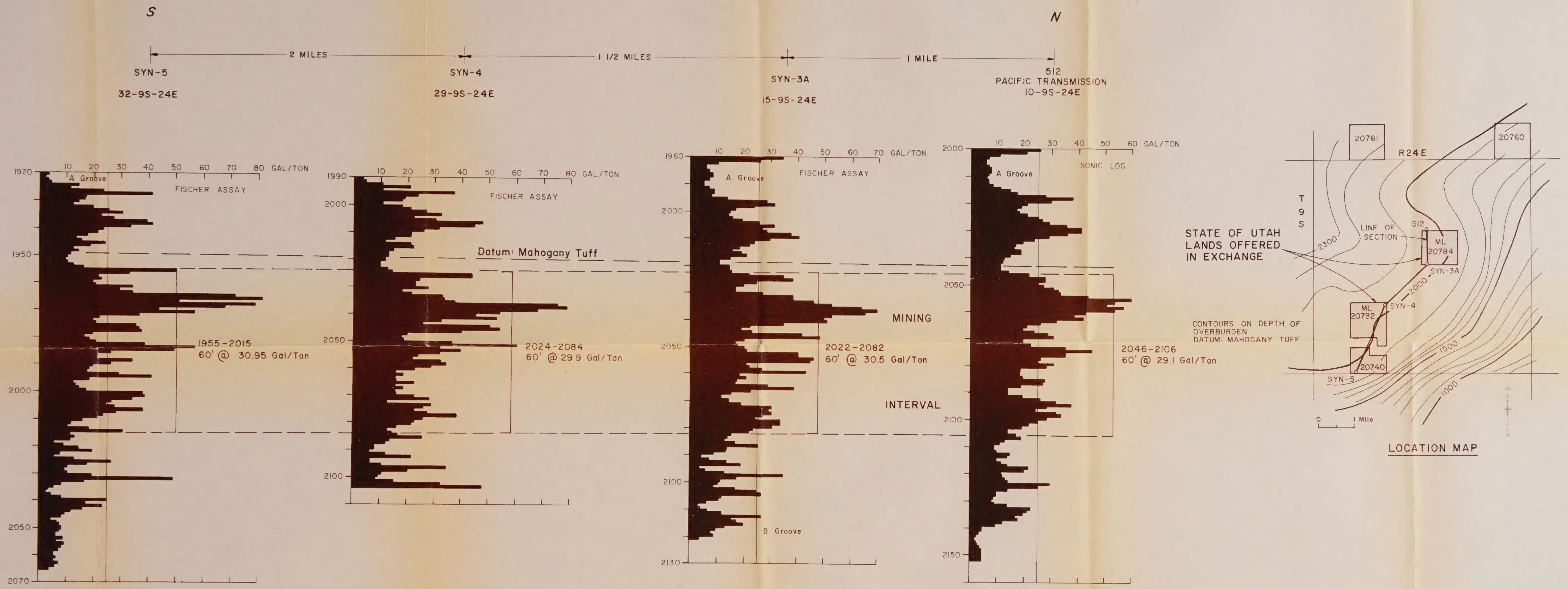


UNITED STATES OF AMERICA
AND
STATE OF UTAH PROPOSED EXCHANGE

SW - NE
STRATIGRAPHIC CROSS SECTION
OF
SELECTED FEDERAL LANDS
T9S, R25E
UINTAH COUNTY, UTAH

J. Rush
Nov. 1981

PLATE I

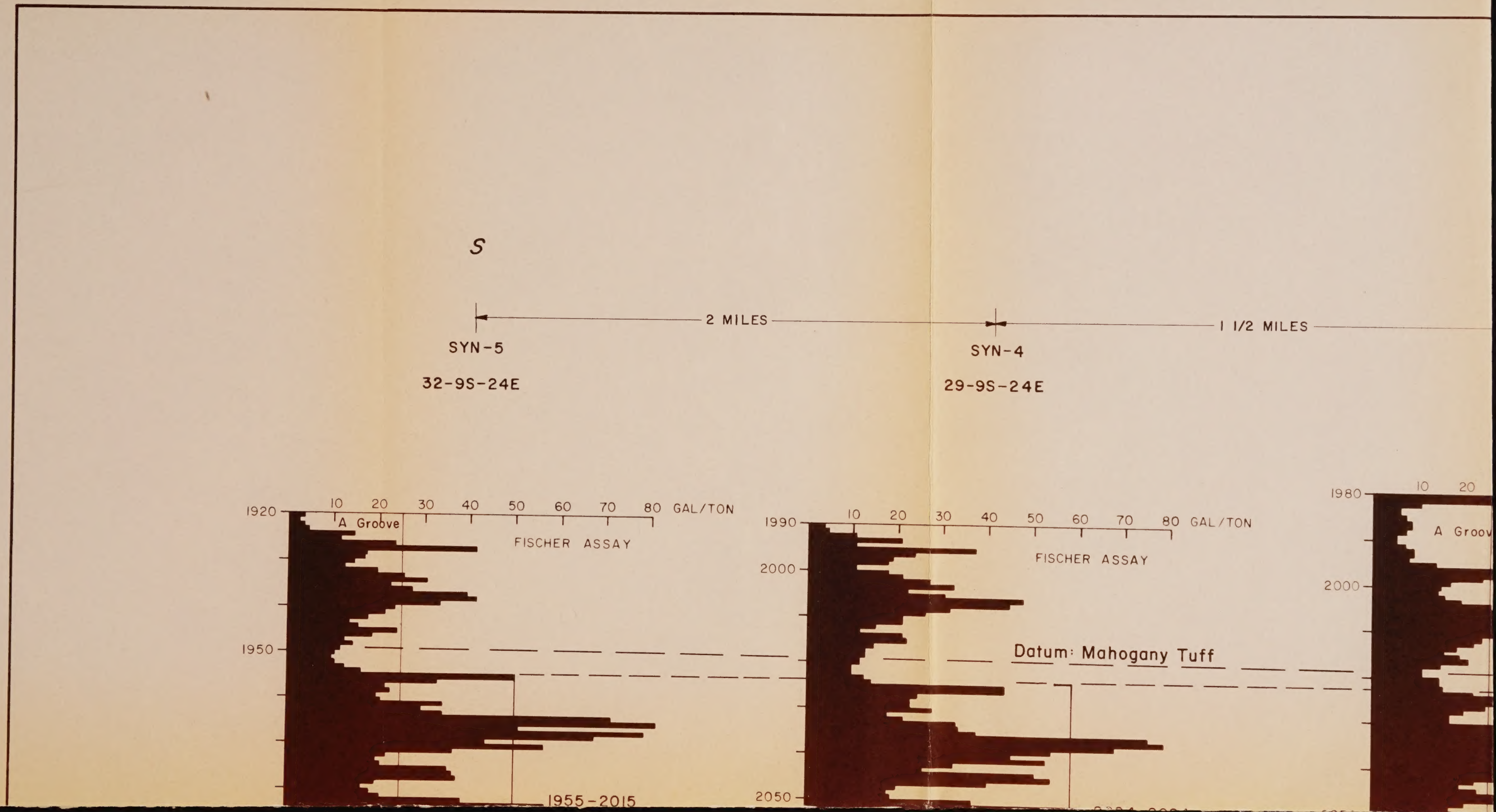


UNITED STATES OF AMERICA
AND
STATE OF UTAH PROPOSED EXCHANGE

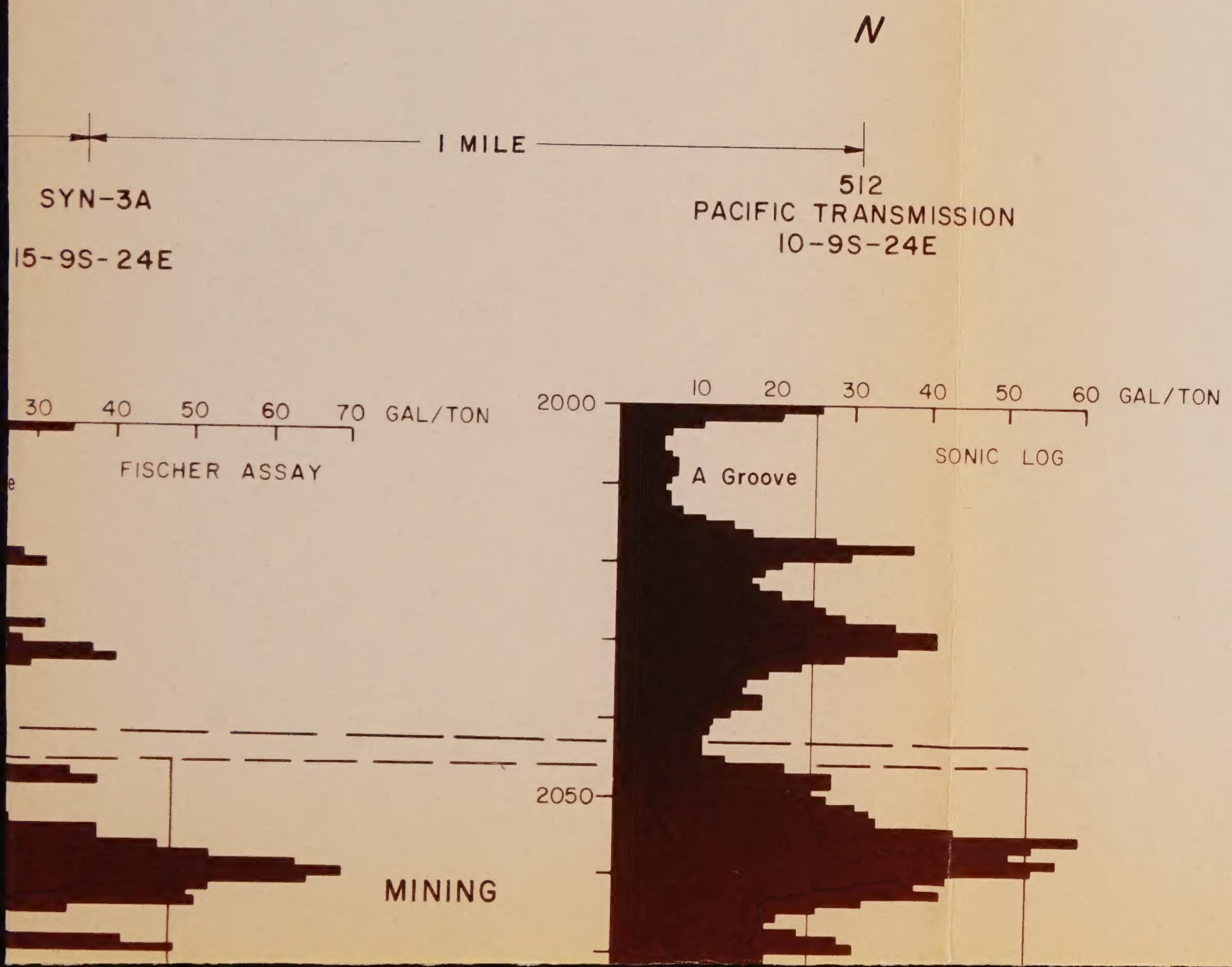
S - N
STRATIGRAPHIC CROSS SECTION
OF
STATE OF UTAH LANDS OFFERED IN EXCHANGE
T 9 S, R 24 E
UINTAH COUNTY, UTAH

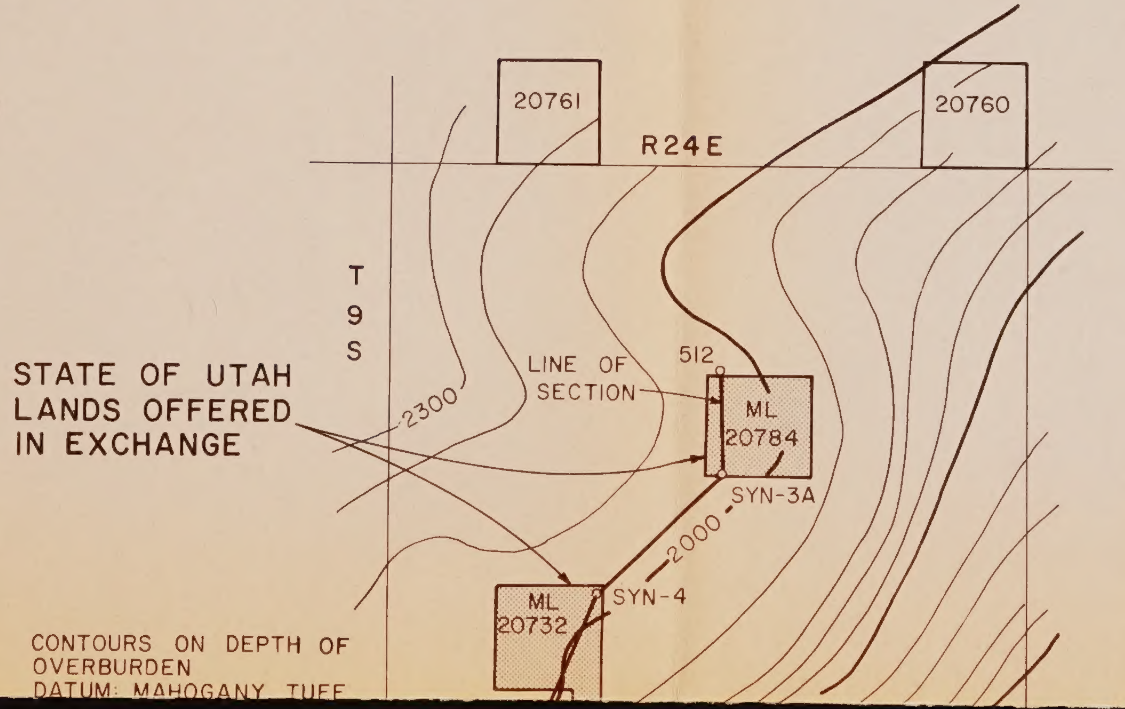
J. Rush
Nov. 1981

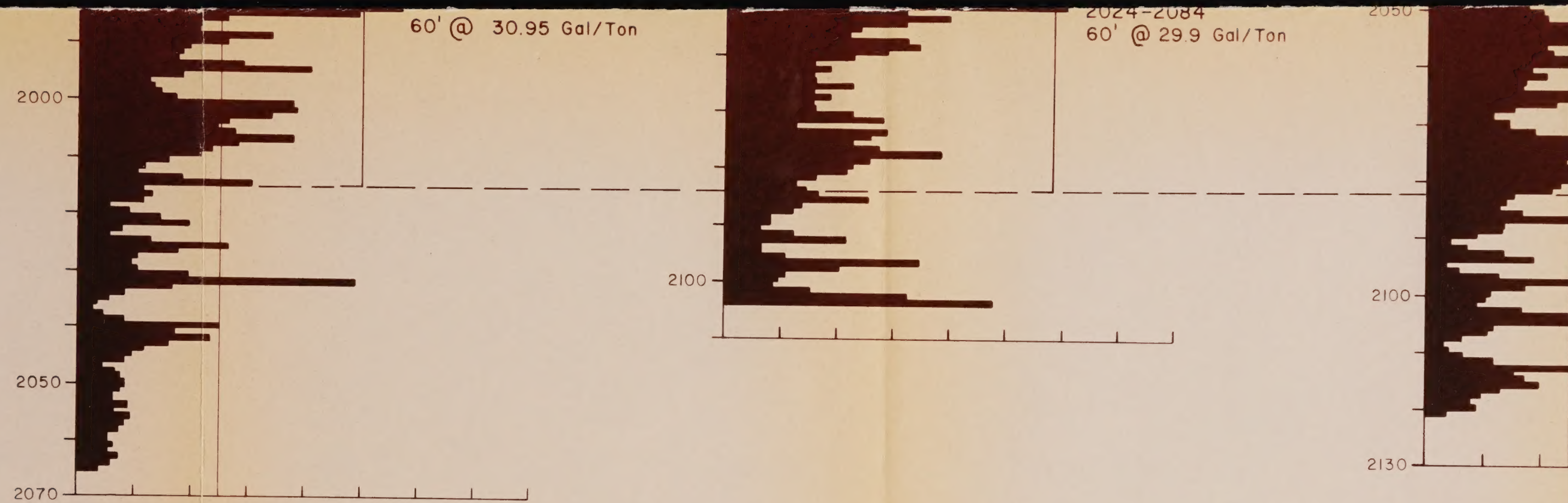
PLATE 2

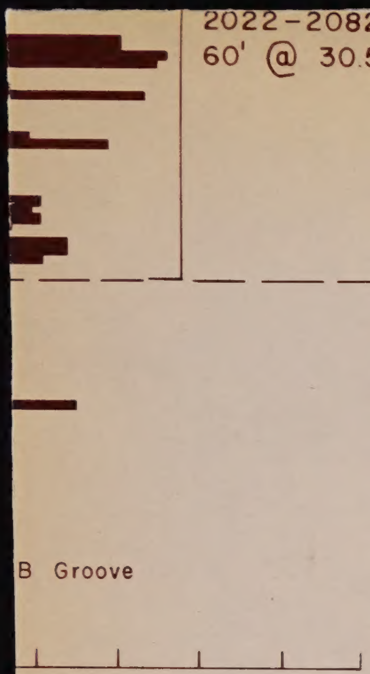


S
2 MILES
1 1/2 MILES
SYN-5
32-9S-24E
SYN-4
29-9S-24E
1920
10 20 30 40 50 60 70 80 GAL/TON
A Groove
FISCHER ASSAY
1950
1955-2015
1990
10 20 30 40 50 60 70 80 GAL/TON
FISCHER ASSAY
2000
2050
Datum: Mahogany Tuff
1980
10 20
A Groov
2000

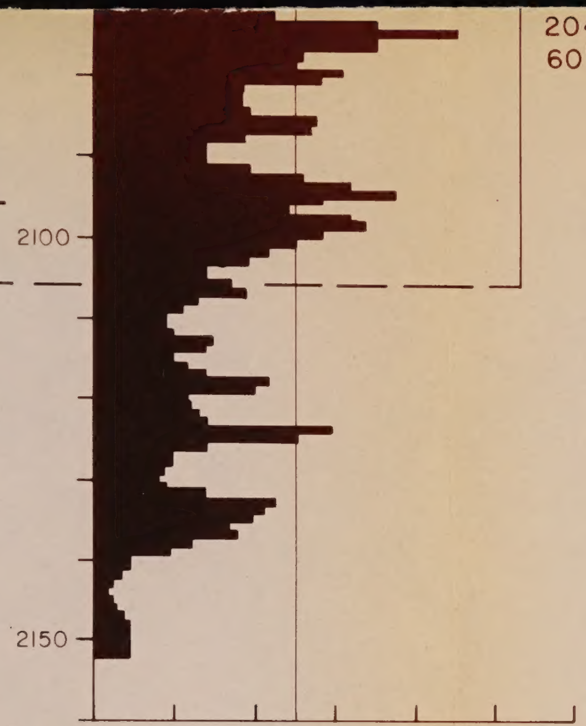

N
SYN-3A
I MILE
512
PACIFIC TRANSMISSION
10-9S-24E
15-9S-24E
30 40 50 60 70 GAL/TON
FISCHER ASSAY
2000
2050
10 20 30 40 50 60 GAL/TON
A Groove
SONIC LOG
MINING

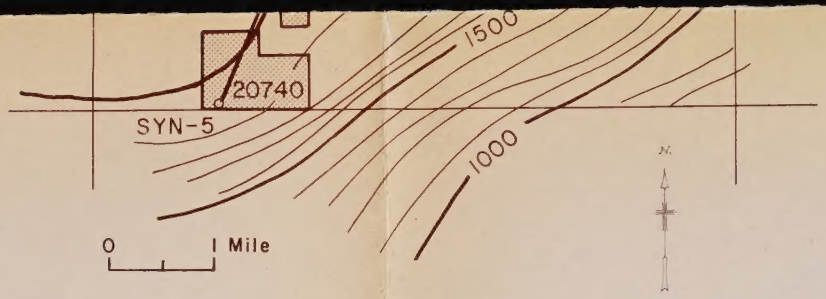

20761
20760
R24E
T
9
S
STATE OF UTAH
LANDS OFFERED
IN EXCHANGE
2300
LINE OF
SECTION
512
ML
20784
SYN-3A
2000
ML
20732
SYN-4
CONTOURS ON DEPTH OF
OVERBURDEN
DATUM: MAHOGANY TUFF


60' @ 30.95 Gal/Ton
2024-2084
60' @ 29.9 Gal/Ton
2050
2000
2100
2100
2050
2070
2130



INTERVAL





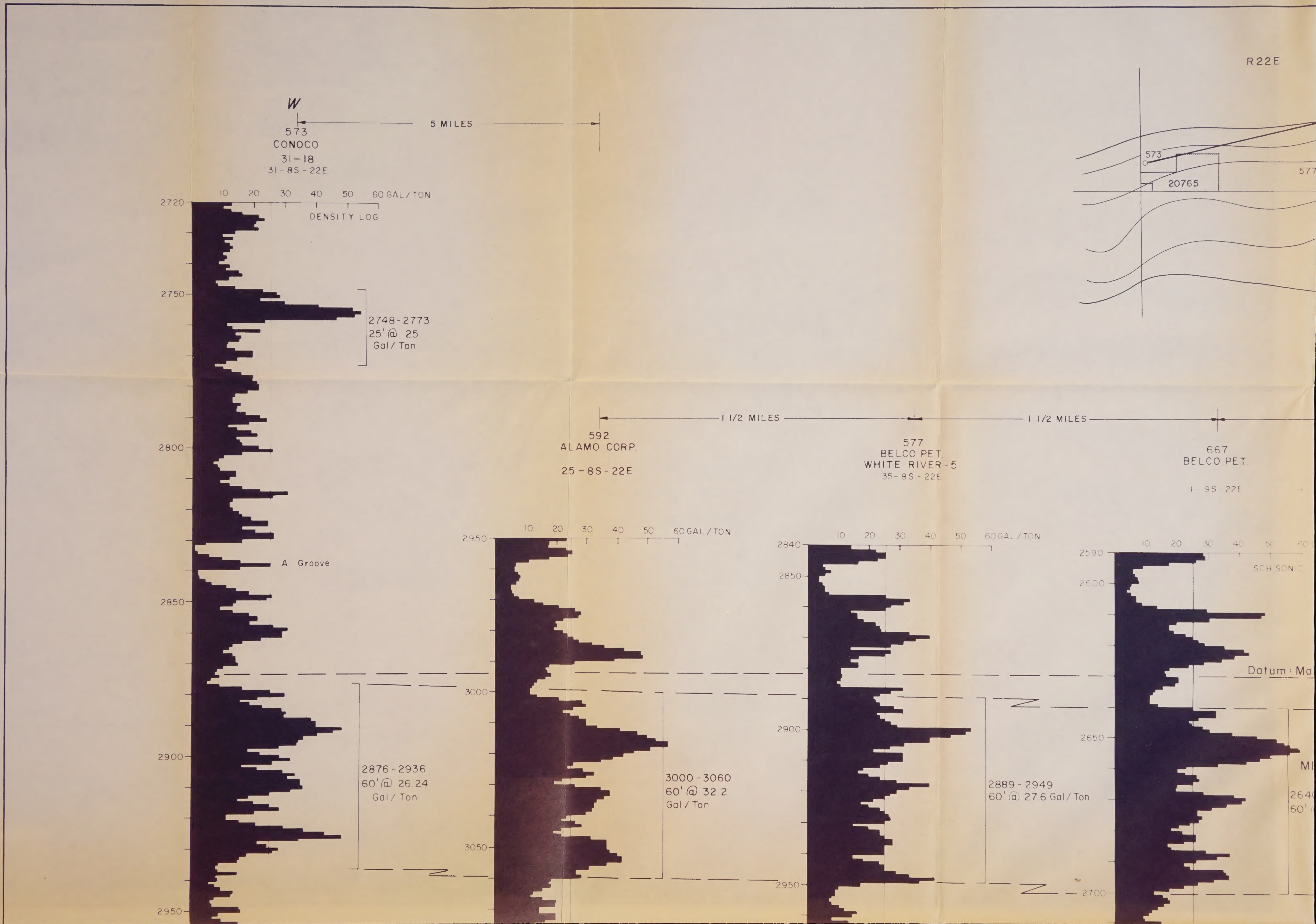
LOCATION MAP

UNITED STATES OF AMERICA
AND
STATE OF UTAH PROPOSED EXCHANGE

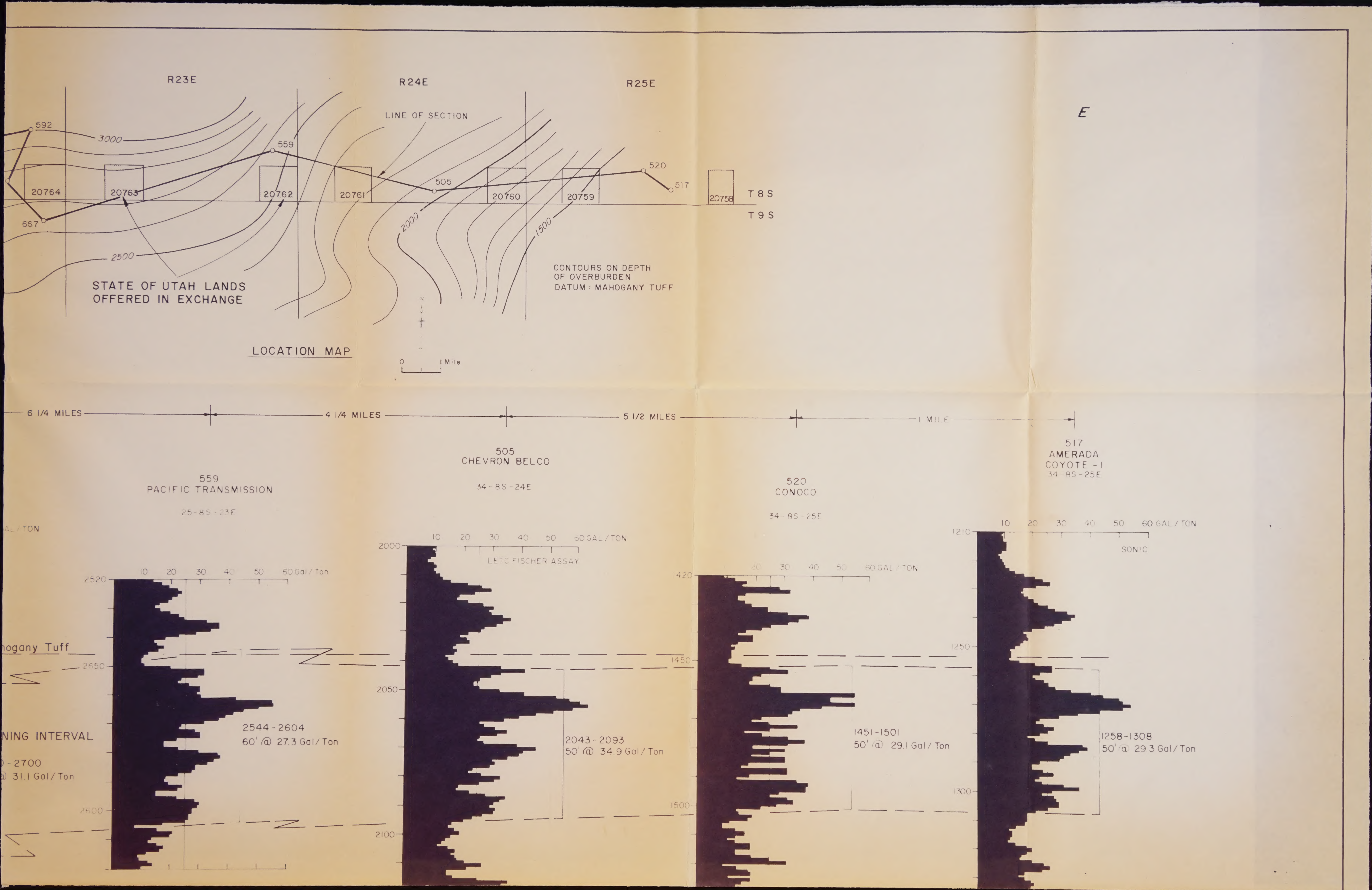
S - N
STRATIGRAPHIC CROSS SECTION
OF
STATE OF UTAH LANDS OFFERED IN EXCHANGE
T 9 S, R 24 E
UINTAH COUNTY, UTAH

J. Rush
Nov. 1981

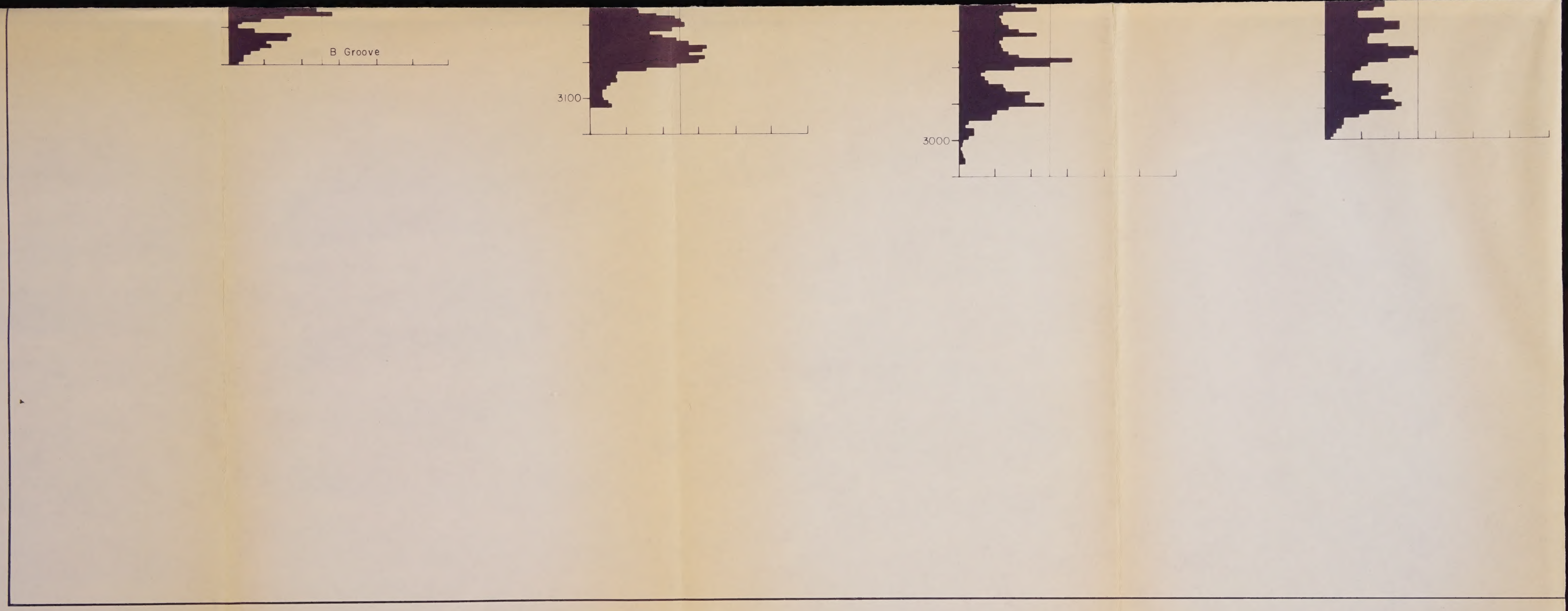
PLATE 2

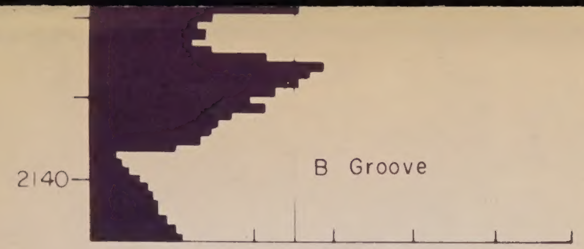


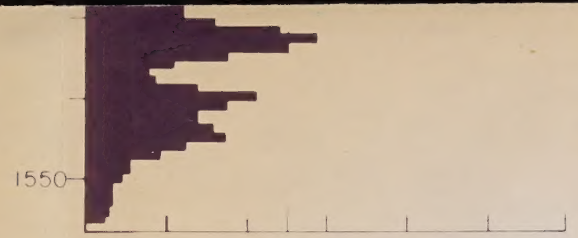
W
573
CONOCO
31-18
31-8S-22E
5 MILES
10 20 30 40 50 60 GAL/TON
DENSITY LOG
2720
2750
2748-2773
25' @ 25
Gal/Ton
2800
A Groove
2850
2900
2876-2936
60' @ 26.24
Gal/Ton
2950
1 1/2 MILES
592
ALAMO CORP.
25-8S-22E
10 20 30 40 50 60 GAL/TON
2950
3000
3050
3000-3060
60' @ 32.2
Gal/Ton
577
BELCO PET.
WHITE RIVER-5
35-8S-22E
10 20 30 40 50 60 GAL/TON
2840
2850
2900
2950
2889-2949
60' @ 27.6 Gal/Ton
667
BELCO PET.
1-9S-22E
2590
2600
2650
2700
SCH SONIC
R22E
573
20765
577

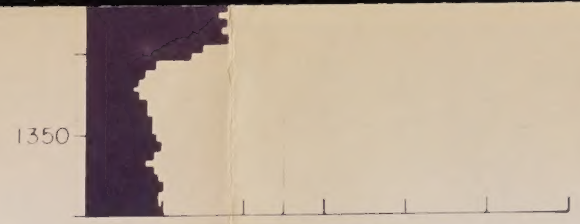


R23E
R24E
R25E
E
592
3000
559
LINE OF SECTION
520
517
505
20764
20763
20762
20761
20760
20759
20758
T8S
T9S
667
2000
1500
2500
CONTOURS ON DEPTH
OF OVERBURDEN
DATUM : MAHOGANY TUFF
STATE OF UTAH LANDS
OFFERED IN EXCHANGE
LOCATION MAP
0
1 Mile
6 1/4 MILES
4 1/4 MILES
5 1/2 MILES
1 MILE
559
PACIFIC TRANSMISSION
25-8S-23E
505
CHEVRON BELCO
34-8S-24E
520
CONOCO
34-8S-25E
517
AMERADA
COYOTE - 1
34-8S-25E
10 20 30 40 50 60 Gal/Ton
10 20 30 40 50 60 GAL/TON
LETC FISCHER ASSAY
20 30 40 50 60 GAL/TON
SONIC
2520
2650
2600
2000
2050
2100
1420
1450
1500
1210
1250
1300
hogany Tuff
NING INTERVAL
-2700
@ 31.1 Gal/Ton
2544-2604
60' @ 27.3 Gal/Ton
2043-2093
50' @ 34.9 Gal/Ton
1451-1501
50' @ 29.1 Gal/Ton
1258-1308
50' @ 29.3 Gal/Ton


B Groove
3100
3000







UNITED STATES OF AMERICA
AND
STATE OF UTAH PROPOSED EXCHANGE

EAST — WEST
STRATIGRAPHIC CROSS SECTION
OF
STATE OF UTAH LANDS OFFERED IN EXCHANGE
T 8 S, R 22 TO 25E
UINTAH COUNTY, UTAH

J. Rush
Nov. 1981

PLATE 3